UNIVERSIDADE DE LISBOA
FACULDADE DE MOTRICIDADE HUMANA

THE IMMEDIATE EFFECTS OF LUMBAR SPINAL MANIPULATIVE THERAPY (SMT) IN TERMS OF KINETIC AND KINEMATIC SYMMETRY OF FUNCTIONAL PERFORMANCE TESTS ON ASYMPTOMATIC PARTICIPANTS

Bruno Araújo Procópio de Alvarenga

Orientador: Professor Doutor António Prieto Veloso
Coorientador: Professora Doutora Filipa Oliveira da Silva João

Tese especialmente elaborada para obtenção do Grau de Doutor em Motricidade Humana na especialidade de Reabilitação

2019

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The immediate effects of lumbar spinal manipulative therapy (SMT) in terms of kinetic and kinematic symmetry of functional performance tests on asymptomatic participants.

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“Intellectuals solve problems; geniuses prevent them.”

Albert Einstein

Dedication

To my beloved Grand Mother and my Grand Father (in memorial), my Mother, my Father, my Sister Pamela, my loved wife Ana and all my friends who have always supported me in this journey

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First and foremost, I would like to thank my supervisor, Professor António Prieto Veloso, for welcoming me into the FMH Biomechanics Laboratory and Neuromechanics research group, and for believing in me and making me confident. Throughout this journey, he has continuously supported my decisions, provided me with endless learning opportunities and introduced me to great colleagues inside the laboratory team, and for that I am ever grateful. He also presented me with various challenges that were essential to the development of new skills and enhancement of existing ones, therefore making me a more independent and confident researcher. I am grateful for his continuous support and encouragement throughout this journey.

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Resumo

Atualmente a natureza competitiva da prática esportiva cria demandas constantes de tecnologias e opções terapêuticas que possam influenciar o desempenho desportivo. De acordo com a literatura, observa se um crescente interesse sobre os efeitos da Terapia de Manipulação Vertebral (TMV) no desempenho desportivo. O foco é melhorar as capacidades individuais em termos de proficiência e consistência de técnicas, especialmente em relação à simetria na performance física. Este foco contribui para melhorar o conhecimento sobre as capacidades individuais, através da triagem de condições músculo-esqueléticas, nomeadamente nas assimetrias bilaterais, que podem influenciar negativamente parâmetros mecânicos e fisiológicos, afetando potencialmente o desempenho esportivo.

Isso requer uma avaliação precisa e confiável de simetria em termos de testes de desempenho físico em ações estáticas, dinâmicas e explosivas. Para atingir esses objetivos na concretização desta dissertação foram realizados três estudos. No primeiro estudo, o estudo preliminar, a simetria de atletas assintomáticos foi medida através de testes de desempenho sobre plataforma de força e com instrumentos de captura de movimento, para avaliar a viabilidade do estudo em medir as mudanças imediatas da terapia de manipulação lombar na simetria, através dos testes: postura estática, agachamento e salto vertical contramovimento. O segundo estudo, estudo prospetivo teste e re-teste foi desenvolvido para estabelecer a fiabilidade intra-avaliador, intra-sessão das medidas de simetria entre a intervenção experimental lombar TMV. Através de dois índices de simetria e de cálculos estatísticos aprofundados, a fiabilidade e reprodutibilidade das medidas foram avaliados neste estudo. O estudo final, o ensaio clínico randomizado controlado, avaliou os efeitos imediatos de uma única sessão de intervenção terapêutica, na simetria de atletas assintomáticos. Os parâmetros biomecânicos cinéticos e cinemáticos foram medidos através de duas plataformas de força, instrumentos de captura de movimento e softwares de processamento e análise dos dados. Neste estudo foram aplicados dois índices de simetria para obter valores globais de simetria nos testes de desempenho, pré e pós as intervenções experimentais TMV e SHAM.

Com base nos resultados obtidos desses estudos, o protocolo metodológico demonstrou ser viável e fiável em medir os efeitos da manipulação lombar na simetria cinética e cinemática, antes e depois das intervenções terapêuticas. Em 90% das variáveis do estudo, os resultados apresentaram boa e excelente confiabilidade absoluta e relativa, e uma pequena manifestação dos erros das medidas, confirmando a assim confiabilidade, reprodutibilidade e a precisão das medidas, em relação às variáveis propostas na nossa investigação.

Nossos achados sugerem que a estratégia terapêutica de correção das disfunções vertebrais lombares através da terapia de manipulação vertebral, produz efeitos imediatos na simetria estática em postura ortostática bipedal.

Em relação às ações dinâmicas, a intervenção lombar TMV não apresentou efeito imediato significativo na simetria em ambos os grupos de atletas assintomáticos. Portanto, nossos resultados demonstram uma melhoria imediata somente na simetria cinética bilateral em postura estática, nomeadamente nas forças de reação ao solo bilateral.

Esses achados sugerem que este protocolo metodológico apresentado nesta tese, apresenta informações relevantes e fidedignas e pode servir como uma ferramenta útil para medir, tratar e avaliar os padrões de simetria cinética no desempenho de atletas assintomáticos, podendo assim também ser significativo no contexto clínico, desportivo e de investigação científica.

Palavras-chave

Terapia de manipulação vertebral, lombar, força de reação do solo, testes físicos, índice de simetria, atletas, assintomáticos

Abstract

The competitive nature of sports practice creates constant demands for technologies and therapeutic options that could influence sports performance. An increasing interest on this theme have been found on literature interventional between sports professionals, clinicians and athletes regarding SMT effects on sports performance. The focus is to enhance individual capabilities in terms of proficiency and consistency of techniques, especially relative to physical performance. This focus contributes to improve knowledge about individual capabilities, through screening of musculoskeletal conditions, such bilateral asymmetries, that could negatively influence a range of mechanical and physiological parameters and consequently athlete's performance. This requires an accurate and reliable assessment of symmetry in terms of overall functional performance tests. In this stand, to achieve this goals, three studies were conducted. In the first study, the preliminary feasibility study, were measure kinetic symmetry by index with asymptomatic athletes over force platform, and motion capture instrument, to quantitatively evaluated the feasibility of the study to measure the immediate effects of lumbar SMT on symmetry in asymptomatic athletes, through use of physical performance tests: static posture, squat movement, and countermovement. The second study, prospective intra-rater, test-retest reliability study, were applied to establish the physical performance tests reliability, reproducibility of kinetic and kinematic symmetry measurements between lumbar SMT intervention through deep statistics evaluations. The final study, randomized controlled trial with two groups of asymptomatic athletes and two symmetry indexes were utilized to measure the kinematic and kinematic biomechanical parameters by force platform, and motion capture instruments, performing physical performance tests: static posture, squat movement, and countermovement.

Based on the obtained results of these studies, our findings suggest that a therapeutic strategy of correcting the lumbar vertebral dysfunctions through lumbar spinal manipulation produce immediately changes of neuro-musculoskeletal system, namely in kinetic symmetry (bilateral lower limbs reaction forces) in static posture. Relative to dynamic trials, lumbar intervention not presented significant immediate effect on symmetry in both group of asymptomatic athlete's participants.

Good to excellent relative reliability were found in 90% of the variables and small manifestation of measurements errors, in all verified variables, confirming study confidence relative to the variables. Thus, our results demonstrated immediate improvement of bilateral kinetic symmetry in static posture trials, thus appear to be clinically and sportive meaningful.

These findings suggest that this methodological protocol may be a useful tool to assess physical performance by kinetic and kinematic symmetry in a clinical and sportive context.

Keywords

Spinal manipulative therapy, physical performance tests, symmetry, ground reaction forces, symmetry index, athletes, asymptomatic

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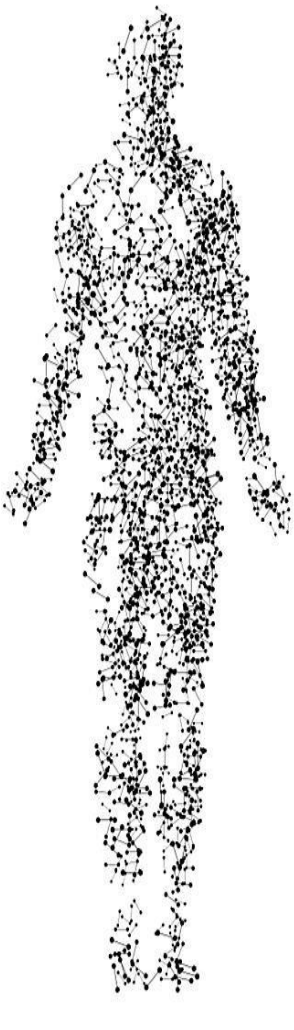
List of Abbreviations

3D	Three-Dimensional
ASIS	Anterior Superior Iliac Spine
CAPES	Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES)
CAT	Thesis Accompanying Committee
CI	Confidence Interval
CM	Center of Mass
CMJ	Countermovement Jump
CT	Computerized Tomography
FMH	Faculty of Human Kinetics
GRF	Ground Reaction Force
ICC	Intra-class Correlation Coefficient
IOC	International Olympic Committee
LGSI	Linear Global Symmetry Index
L5S1	Fifths lumbar and first sacral
LAC	Left Acromial
LASIS	Left Anterior Iliac Spine
LHEEL	Left Heel
LILC	Left Iliac Crest
LLK	Left Lateral knee
LLMA	Left Lateral Malleolus
LMK	Left Medial Knee
LMMA	Left Medial Malleolus
LMT	Left Metatarsus
LOA	Limits of Agreement
LPSIS	Left Posterior Iliac Spine
LRIB	Left Rib
LSK	Left Shank
LTH	Left Thigh
LUMB	Lumbar spine
MDC	Minimal Detectible Change
MEP	Motor Evoked Potentials
MET	Metabolic Equivalent
MRI	Magnetic Resonance Imaging
SI	Symmetry Index
SEM	Standard Error of Measurement
SMT	Spinal Manipulative Therapy
STER	Stern
RAC	Right Acromial
RASIS	Right Anterior Iliac Spine
RCT	Randomized Clinical Trials
RHEEL	Right Heel
RILC	Right Iliac Crest
RLK	Right Lateral Knee
RLMA	Right Lateral Malleolus
RMK	Right Medial Knee
RMMA	Right Medial Malleolus
RMT	Right Metatarsus
ROM	Range of Motion
RPSIS	Right Posterior Iliac Spine
RRIB	Right Rib
RSK	Right Shank

RTH	Right Thigh
T12L1	Thoracic twelve and first lumbar
TMS	Transcranial Magnetic Stimulation
VAD	Vertebral Artery Dissection
WFC	World Federation of Chiropractic
WHO	World Health Organization
MOCAP	Motion Capture System
COP	Center of pressure
COM	Center of Mass

General Introduction



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Background

The actual sports practice routine, with increase of the competitiveness and continuous search for the best performance, several athletes have been suffering repeated with biomechanics overload, creating musculoskeletal problems that negatively influence generating decrease in biomechanics parameters, such as muscle strength and range of motion, affecting physical and sports performance, in training or competitions routine.

This reality is considered problematic and generates a wide area of interest, with a continuous demand for technologies and therapeutics options, in favor of physical performance enhancement and prevention of injuries in athletes of different levels, conditions and sports modalities.

In our investigation, the technology utilized were from Biomechanics resources, creating the biomechanics model, thru of high recommended and validated instruments to capture 3D motion capture by software´s of analysis and processing of the kinetic and kinematic variables. The strategy used to measure physical performance, was based on performance tests assessment through functional actions during test-retest static posture, free squat movement and countermovement jump high – (CMJ) task), commonly utilized in clinical and sportive context, acting such a “barometer” of the neuro-musculoskeletal system.

The therapeutic utilized was through Spinal Manipulative Therapy (SMT), mostly practiced by doctors of chiropractic, has been increasing utilized in sports practice, being recognized safe and effective therapy, in terms of athletes’ rehabilitation on individuals without contraindications. SMT purpose is correcting biomechanics dysfunctions on spine, through the application of high-velocity, controlled low-amplitude movement, within the paraphysiological space, beyond the passive joint range of motion on spinal articulations, reducing internal mechanical stress, and restoring restricted movements found along the spine.

Nevertheless, all these biomechanical dysfunctions could interfere on physical performance, especially on functional performance tests proposed in our investigation. According literature interventional, SMT change the neuro-musculoskeletal system through restoration of pre-existing and/or existing vertebral or articular dysfunctions. In this stand, we therefore hypothesized in our investigation that correcting pre-existents lumbar vertebral dysfunctions through SMT intervention, could influences a range of biomechanics parameters, as kinetic and kinematic symmetry of functional performance tests in health and asymptomatic participants.

Despite of this, very little is known about the immediate effects of lumbar SMT on symmetry parameters in terms of performance test assessments in asymptomatic athletes. Few studies have been focused on quantitatively measure biomechanics responses associated with the SMT on bilateral symmetry, especially in a group of health and asymptomatic athletes. Still limited evidence if SMT could be beneficial in this context. Therefore, to contribute of some of this gaps, attending the necessity for recent clinical trials studies, focusing on the way to explain how the spinal structures can react to external forces and how these forces can affecting physical performance through functional tests, our pioneer investigation, aimed to quantitatively measure the immediate changes on neuro-musculoskeletal system, in terms of local and global levels of symmetry, through functional performance tests on health and asymptomatic athletes participants.

Introduction

The competitive nature of sports practice creates constant demands for technologies and therapeutic options that could influence sports performance that is defined as a combination of specific physical routines or procedures performed by someone who is trained or skilled in a physical activity and influenced by physiological, and sociocultural factors.

Commonly, in sports rehabilitation, the focus of doctors, trainers and athletes, is always to enhance individual capabilities in terms of proficiency and consistency of techniques, especially relative to functional movement tasks, normally practiced by athletes from different levels and modalities in daily training and competition routine (Taimela et al., 1999). This focus contributes to improve knowledge about individual capabilities, through screening of musculoskeletal conditions (Bergeron et al., 2015; Ljungqvist et al., 2009), by clinical protocols that's include functional movement tasks, highly recommended a periodic health evaluation,(Ljungqvist et al., 2009;Chimera & Warren, 2016) to identifying, controlling and minimizing the intrinsic and extrinsic injury risk factors (Soligard et al., 2016), (Bergeron et al., 2015) that affect the quality of movements on daily training and competition routine, (Theberge, 2008) mainly as a result of repetitive biomechanical demands (Smith, Sc, Cox, & Ph, 2000; Bartlett, 2005; Smith & Cox, 1999).

Kinetic and kinematic symmetry can be measured through functional performance tests, that are often used as indicators of the athlete's performance (Clark, 2001; HansJoachim Menzel,et al, 2013; Impellizzeri & Marcora, 2007; Valderrabano et al., 2007).

Functional asymmetries in athletes could be associate with performing a task asymmetrically, either on kinetic and kinematic symmetry movements, or both, in static and/or dynamic actions (Gregory, & Thiel, 2000, Pickar & Bolton, 2012).

Static and dynamic movements symmetry (Almeida et al., 2016; Burnett et al., 2011; Menzel et al., 2012; VanZant, McPoil, & Cornwall, 2001; Vienneau, 1989) have been utilized in studies with high performance athletes (HansJoachim Menzel, Mauro H. Chagas, Leszek

A. Szmuchrowski, Silvia R.S. Araujo, Andre G.P. de Andrade, 2013; Impellizzeri, F. M., Bizzini, M.,et al 2008; Impellizzeri, Rampinini, Maffiuletti, & Marcora, 2007; Silva, Salvador, & Freitas, 2015) in several tests, have been demonstrated good to excellent reliability (Atkinson & Nevill, 1998; Fairus, Joseph, Omar, Ahmad, & Sulaiman, 2016; Impellizzeri et al., 2007; Menzel et al., 2012; Tsushima, Morris, & Mcginley, 2003) when applying which propose of statistically measure biomechanical parameters and instruments (HansJoachim Menzel, et al, 2013; Impellizzeri, F. M., Bizzini, M., Rampinini, E., Cereda, F. and Maffiuletti, 2008; Menzel et al., 2012)

Athletes with bilateral asymmetries condition, commonly present biomechanical joint/spinal dysfunctions (Shekelle, P.G. 1994; Lelic et al., 2016; G. R. Tomkinson & Olds, 2000) as a result of structural or functional impairments, that could consequently produce decrease in kinetic and kinematic parameters, bilaterally or unilaterally, during physical performance movements, or at least decrease in all physical performance potential related (Botelho, Alvarenga, Molina, Ribas, & Baptista, 2017).

Bilateral symmetry differences could be related with structural factors (McCaw & Bates, 1991; Almeida, Lima, et al., 2016), structural or congenital ones, presenting in cases of leg length inequality, (Gurney, 2002) and functional factors (Almeida, Prudente, et al., 2016; Błazkiewicz et al., 2014; Cho, 2013; Fousekis, Tsepis, & Vagenas, 2010; Maly, Zahalka, Bonacin, Mala, & Bujnovsky, 2015; McGrath et al., 2016; G. R. Tomkinson & Olds, 2000; Yoshioka et al., 2010) McGrath et al., 2016). Previous studies (Grant R. Tomkinson et al., 2003) have showed that in adult human males, symmetry is positively associated with height, body mass and physical performance.

In this regard, an association in musculoskeletal disorders, such bilateral asymmetries (14,15), could negatively influence a range of mechanical (Lehman, 2004; Margareta Nordin, 2001; Smith, Sc, Cox, & Ph, 2000) and physiological parameters (Fryer G, Morris T, 2004, Maly, Zahalka, Mala, & Cech, 2015; Marshall et al., 2015; Tomas Maly, Frantisek Zahalka, Dobromir Bonacin 2015) of symmetry (McGrath et al., 2016) (Almeida et al., 2016), could thus potentially influence athletic performance (Tomkinson, Popović, & Martin, 2003) (Yoshioka, Nagano, Hay, & Fukashiro, 2010)

According clinical and sportive scientific studies founds in literature and according our previous research related with bilateral symmetry in functional tests, in health and asymptomatic participants, were considered 15% of asymmetry as a normal differences inter-limbs. Noyes et al (Noyes, Barber, & Mangine, 1991) states that 85% of bilateral symmetry is considered normal in healthy individuals, but the same maybe not happen with elite athletes (Noyes et al., 1991).

In this stand, several authors calculated the bilateral symmetry in elite athletes over force platform, motion capture and isokinetic instruments, calculating symmetry by index in gait and vertical jumps functional tasks. (Almeida et al., 2016; Menzel HJ, Chagas MH, Szmuchrowski LA, Araujo SR, de Andrade AG, 2013; Noyes, Barber, & Mangine, 1991).

These researchers concluded that symmetry index values higher than 10% indicates asymmetry, and values higher than 15% points out an important asymmetry. By other hand, Herzog et al (Herzog W, Nigg BM, Read LJ, 1989) investigated the normal upper and lower limbs gait asymmetries and found symmetry ranged from 4 to 13%. This information's are important to verify the existence of bilateral asymmetries in functional tests (Fousekis, Tsepis, & Vagenas, 2010; Linthorne, 2001; McGrath et al., 2015) and also to assess training effectiveness and prevention/ rehabilitation programs outcomes (Cordova & Armstrong, 1996; Nigg, Vienneau, Maurer, & Nigg, 2013; Robinson, Herzog, & Nigg, 1987).

According literature, and to the best of our knowledge, no studies have been performed with health and asymptomatic athletes integrating knowledge's about clinical rehabilitation, sports performance and clinical biomechanics, with focus on accurately measure and detect abnormalities on kinetic and kinematic symmetry, under interventional protocol (Hannon, 2004) thru therapeutic interventions proposed to support it.

Our recent systematic review of literature (Botelho, Alvarenga, Molina, Ribas, & Baptista, 2017) about the theme, detect a growing number of studies associating SMT with performance tests in athletes of different practice levels (Botelho & Andrade, 2012; Humphries et al., 2013; Costa et al., 2009; Alvarenga B, Facchinato A. P & Brian K.L 2012) (Shrier, Macdonald, & Uchacz, 2006). Spinal Manipulative Therapy (SMT) is a safe and considerably effective therapy for musculoskeletal disorders that has increasingly been used in sports (Botelho, Alvarenga, Molina, Ribas, & Baptista, 2017) with athletes of different levels and modalities, applied by clinicians, including physiotherapist and chiropractors in sports competitions around the world, such as Olympic game events, as part of the medical services available for the teams.

SMT purpose is to correct spinal joints biomechanical dysfunctions using a high-velocity, low-amplitude movement, applied at the paraphysiological space, beyond the passive joint range of motion (Chapman-Smith, 2001; Herzog, Scheele, & Conway, 1999). The literature has consistently indicated that SMT may promote changes in the neuro-musculoskeletal system, by altering the sensory and neurological signals, (Pickar & Bolton, 2012) having an impact on proprioceptive primary afferent neurons in paraspinal tissues.

(D.-Y. Cao & Pickar, 2011; Colloca, Pickar, & Slosberg, 2012; DeVocht, Pickar, & Wilder, 2005; J. G. Pickar & Bolton, 2012; Joel G. Pickar & Kang, 2006; Joel G. Pickar, Sung, Kang, & Ge, 2007; Joel G Pickar, 2002) thus improving the physiological function and changing the local and peripheral motor control system. (D.-Y. Y. Cao, Reed, Long, Kawchuk, & Pickar, 2013; Cramer, Budgell, Henderson, Khalsa, & Pickar, 1997; Ge. W.; Pickar, 2008; Kang YM, Choi WS, 2002; J G Pickar & Wheeler, 2001; Sung, Kang, & Pickar, 2005).

Therefore, SMT causes increases of neurological actions of the neuro-musculoskeletal system manifesting through the structures of the vertebral spine involved in the mechanisms of transmission and coordination of the movements between the upper and lower extremities (Haavik et al., 2017; Pickar & Bolton, 2012).

An increasing interest on this theme have been found on literature interventional between sports professionals, clinicians and athletes regarding SMT effects on sports performance (Botelho, Alvarenga, Molina, Ribas, & Baptista, 2017). Despite of this fact, remains disagreement between findings, revealing a number of clinical trials assessing SMT effects in performance tests, without consistency and scientific validity. Actually, this is a problem because many of instruments and measurements techniques related with symmetry measurements on physical performance tests are not fully establish.

The currently literature indicates the importance in analyzing the current SMT neurophysiological evidence, in relation to perform the randomized clinical studies, in a proper way. Additionally, is highly recommended perform deep statistics planning and calculations to complement randomized clinical methodologies and measured outcomes, because studies with large measurements error detectible and low reliability especially for clinical and sportive context may lead to underestimation drowning out real effects.

Although, in our studies, were quantitatively measure the immediate effects of lumbar SMT on kinetic and kinematic symmetry in recreational and elite asymptomatic athletes, through of the use of three commonly used functional performance tests: static posture, free squat movement, and Vertical Jump Countermovement, to after statistically evaluate, the relative and absolute reliability, minimal detectible changes of biomechanics variables measured, through developed statistical pack of reliability. Our investigations seek to improve better understanding the mechanisms behind of the immediate changes in symmetry patterns after lumbar spinal manipulative therapy, when applied therapeutically in health and asymptomatic athletes. This required an accurate and reliable evaluations of the symmetry of the whole and for that reason, in our experimental study, were utilized two indexes of symmetry, kinetic and kinematic ones, in static and dynamic actions, acting at a global level.

According with possibility of the use of statistical resources and biomechanics laboratory with high technology instruments and software's of tridimensional motion capture systems, capable to evaluate the immediate effects of SMT on kinetic and kinematic athletes' symmetry, this present thesis could definitely contribute to scientific, sportive and clinical communities with new information's about bilateral symmetry of asymptomatic athletes and clinical approaches.

The association between SMT therapeutic intervention and symmetry of athletes never were deeply made, thus through our investigations our results indicated possible causal effect between these variables. In this way, to describe the most relevant findings product of our scientific studies collection were presented following bellow.

Preliminary feasibility study (Study 1): Our preliminary investigation results showed that statistical significant differences were found in lumbar SMT, only for static position symmetry for this group of asymptomatic athletes' participants. However, a great increase in bilateral symmetry percentage on static position was seen, but none in dynamic tests.
This preliminary study demonstrates that a larger study to evaluate if lumbar SMT changes symmetry is feasible.

Intra-rater, test-retest reliability study (Study 2): Our findings indicated good to excellent relative reliability in 90% of the variables and small manifestation of measurements errors, in almost all verified variables. The reduced values of minimal detectible changes found in all measure outcomes, confirmed the study confidence relative the variables.
However, acceptable values of relative and absolute reliability were found by the observer on test-retest symmetry measurements in athletes.
Physical performed tests symmetry demonstrated to be reliable method to measure symmetry in asymptomatic athletes, but further reliability studies are needed to address the study limitations.

Randomized Controlled Trial study (Study 3): Our findings indicated that asymptomatic athletes' participants presented static bilateral asymmetry prior the interventions, from pre-16,3%, and after interventions, reduced significantly to 3,7%, immediately post lumbar SMT intervention. However, lumbar (SMT) intervention produced immediate effects on static symmetry; but the same effects were not found in dynamic tests (squat and CMJ). No statistical significant effects were found in symmetry, pre-to-post SHAM in any of the physical performance tests.
Thus, in our randomized controlled study, lumbar SMT produced immediate effects on symmetry in static standing position when applied therapeutically.
This study expects to demonstrate that the single-session strategy of correcting the lumbar vertebral dysfunctions through lumbar SMT can effectively produce immediate effects in static symmetry. Adding new information regarding to the static symmetry influenced by lumbar SMT intervention, these findings seem to be useful for clinical context in rehabilitation programs of athletes.

Aims and outline of the thesis

According to the best of our knowledge, no studies in literature have been performed with asymptomatic athletes integrating knowledge's about clinical rehabilitation, sports performance and clinical biomechanics, with focus on kinetic and kinematic symmetry parameters, and how obtain accuracy of this measurements to draw consistent results.

One problem however, is that many of instruments and measurements techniques related with physical performance tests are not fully establish, been used in many of cases without validation and without strategies to resolve the potential biases. Additionally, studies with large measurements error detectible and low reliability especially for clinical and sportive research context may lead to underestimation drowning out real effects.

This lack of opportunity gives us the way to investigate the real effects on the musculoskeletal system and how much reliable is the rater/observer, measures and instruments. According with possibility of the use of statistical resources and biomechanics laboratory with high technology instruments and software's of tridimensional motion capture systems, capable to measure the immediate effects of SMT in athletes' symmetry, this present thesis could definitely contribute to scientific, sportive and clinical communities with new information's about the acute association of lumbar spinal manipulative therapy on kinetic and kinematic symmetry parameters.

Study 1 – Preliminary feasibility study aims

The aim of this preliminary study (n:13) was to assess the feasibility of a study to measure the immediate changes of lumbar spinal manipulative therapy (SMT) in bilateral symmetry on physical performance tests.

Study 2 - Intra-rater, test-retest reliability study aims

The aim of this present study study (n:20), was to assess the intra-rater and test-retest reliability of physical performance tests symmetry between lumbar spinal manipulation in asymptomatic athletes. Through statistical calculations were identified the mean, standard deviation, intra-class correlation coefficient (ICC), standard error of measurements (SEM), limits of agreements (LOA) and also the minimal detectable changes (MDC).

Study 3 - Randomized controlled trial study aims

The aim of this single blinded, randomized controlled trial study (n:40), was to quantitatively measure the immediate effects of lumbar SMT in symmetry through of three commonly used physical performance tests: static position, squat movement, and countermovement jump.

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Study 1

A preliminary feasibility study to measure the immediate changes of bilateral symmetry after lumbar spinal manipulative therapy (SMT) in asymptomatic athletes

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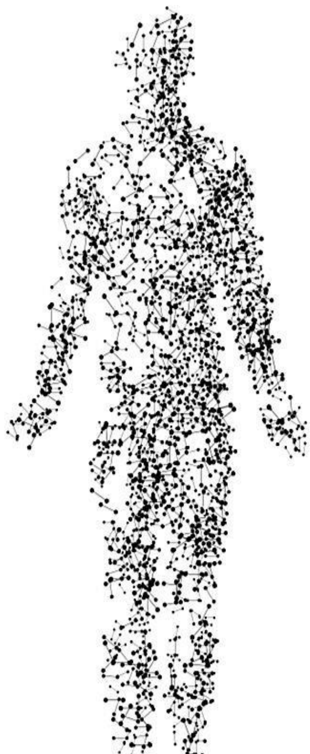

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Abstract

Objectives: The purpose of this study was to assess the feasibility of a study to measure the immediate changes of lumbar spinal manipulative therapy (SMT) in bilateral symmetry on physical performance tests.

Methods: Thirteen asymptomatic athletes' participants were included in this study. Each participant underwent a clinical and physical evaluation for inclusion according eligibility criteria. The immediate changes of lumbar SMT on physical performance tests symmetry were quantitatively measured pre and post-intervention. The Kolmogorov-Smirnov statistical test was used to assess normally distributed date. Student's t test ($p<0.05$) was used to compare pre-to-post intervention outcomes. Statistical significance ($P < 0.05$) of instants of therapy were calculated by physical performance tests, pre-and-post SMT.

Results: Statistical significant difference in pre (mean:14.4%) and post-lumbar SMT (mean:3.7%) were found in static symmetry, but the same results were not found in dynamic trials namely in squat and countermovement jump. The acceptability to participants of the treatments were total. All selected participants completed the study, and none of them reported complaints during participation.

Discussion: The asymptomatic athletes' participants presented initially bilateral asymmetry values, such as described in the literature.[7,27,77] After lumbar SMT, this values decreased significantly in static posture. Thus, our findings therefore showed that lumbar SMT changes static symmetry, through mechanisms suggested by Herzog[77,82,83]and Pickar.[84]

Conclusions: The results of this preliminary study showed that statistical significant differences were found in lumbar SMT, only for static posture symmetry for this group of asymptomatic athletes' participants. A great increase in bilateral symmetry on static symmetry percentage was seen, but none in dynamic tests; which deserves further investigations. This study demonstrated the feasibility to measure the immediate changes produced by lumbar SMT in symmetry. Nevertheless, this preliminary feasibility study demonstrated that a larger study to evaluate if lumbar SMT affects bilateral symmetry is feasible.

Keywords: musculoskeletal disorders, biomechanics phenomena, lumbar spine, spinal manipulative therapy, ground reaction forces, symmetry index.

Introduction

Musculoskeletal disorders in athletes, including spinal biomechanical dysfunctions,[1–4] which are often asymptomatic[2,5], are believed to negatively influence physical performance in terms of symmetry.[2,6–10]

Tomkinson et al[3,11] suggested that athletes who are symmetric also have improved physical performance. Asymmetric athletes may thus show decreased physical performance or have an increased risk for injury as a result of favoring the bilateral asymmetry of the body.[3,9,11–16]

During athletic performance in static and dynamic actions, musculoskeletal coordination[17] forms the basis for symmetry and control as the compression forces are transferred toward the spine, which stabilizes keeps the upper body balanced and upright.[8,12,18] The lumbar spine is active in absorbing and controlling the force being transmitted through the body and down the biomechanical chain, as a result of the ground reactive force acting on the limb.[8,19,20] Thus, athletes with bilateral asymmetry[13,16,21,22] may exhibit a unilateral or bilateral decrease in biomechanical parameters when performing a task asymmetrically. [11,13,23–32]

Bilateral asymmetry has been shown to be indicative of spinal abnormalities[8,33], and, in clinical and sportive contexts, the ability to detect abnormal biomechanical parameters is extremely important in order to focus on restoring normal function through appropriate treatment strategies. [2,34–38] In this sense, we hypothesize that is feasible to measure if a single therapeutic strategy for correcting spinal biomechanical dysfunctions through a lumbar spinal manipulative therapy (SMT), could produce immediate changes in symmetry of physical performance tests in asymptomatic athletes.

SMT is recognized as a safe and effective therapy for musculoskeletal disorders that has been increasingly used in sports and has been useful therapeutic strategy for biomechanical joint dysfunction, especially that involving the spine.[1,2,39–50] SMT is commonly practiced by doctors of chiropractic to correct biomechanical dysfunction of spinal joints. This technique uses high-velocity, low-amplitude movement applied at the paraphysiological space, beyond the passive joint range of motion. [38,41,51–55]

A recent systematic review[35] of the literature found several studies that associated SMT with sportive performance,[25,56–67] but none focused on the athletes' symmetry tests, influenced by SMT. Therefore, the purpose of this preliminary study is to assess the feasibility of a study to measure the immediate changes in symmetry after SMT intervention, to determine if is feasible to carry on the main study if the objective of this preliminary feasibility study was fulfilled for conducting a large study.

Methods

Study design

A preliminary feasibility study was conducted.

Sample size

Based on prior sample size calculations, (n = 13) athletes (9 women and 4 men) from different sports participated in this study. The sample size was calculated using GPower®[68]

software, to determine the minimal sample size required for this type of study.[69] An one-tailed, a priori t-test was performed to evaluate the difference of the two dependent measurements with an effect size of 0.8, alpha of 0.05, and statistical power[68,69] of 0.8, obtained from the sample of 13 participants. According to GPower®[70]calculations, the effect size conventions stated that d = .80 is considered a large effect.

Recruitment and informed consent

The participants were athletes recruited through public advertisements at the Center of High Performance, University of Lisbon, Portugal, according to the eligibility process. All participants were volunteers that signed an informed consent prior to enrolment.

Ethical standards were applied according to the Helsinki Declarations, and the research protocol was approved by the Faculty of Human Kinetics, University of Lisbon, Ethics Research Committee.

This preliminary study was conducted and registered as a clinical trial to verify the feasibility[71] of the study to measure the immediate changes in bilateral asymmetry after SMT intervention to the lumbar spine. The focus was more on the average percentage change between pre- and posttests, which is represented by the symmetry index (%), and not on the analysis of specific categories of physical ability or sportive performance.

All participants completed the study, and none reported complaints during participation.

Sample characteristics

All selected participants were asked to fulfill the eligibility criteria. Total acceptance between participants.

The participants were athletes of any gender, aged between 18 and 35 years, asymptomatic, and had a normal clinical evaluation.[72,73]

Each participant underwent a clinical and physical evaluation, performed by one experienced physiotherapist and a chiropractic doctor to verify suitability for inclusion. To ensure that the athletes complied with the eligibility criteria, they were required to undergo a chiropractic evaluation, thought recognized physical and orthopedic examinations[2,52,74] which was administered at the biomechanics laboratory.

Participants who experienced any changes in their training routine or competition during the study, had a history of lumbar and/or lower limb surgery, or were treated with manual therapy at any time during the study were excluded.[72]

Study protocol

Prior to data acquisition, personal and anthropometric data (gender, age, body weight, and height) of each participant were recorded. Before the performance tests, each participant was given 5 minutes to become familiar with the tasks and the data collection procedures. The participants were then asked to participate in physical tests sequence before (pre-test) and after (post-test) the lumbar SMT intervention, as a described on figure 1.

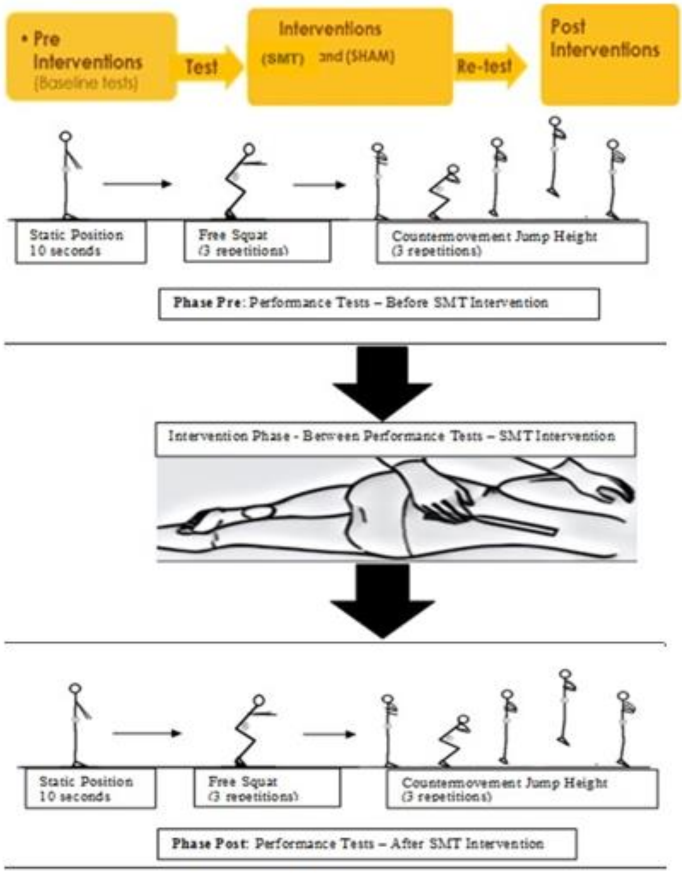

Figure 1 - Physical performance tests sequence.

Assessments included a physical test symmetry sequence (static standing position, free squat, and CMJ jump) as well as a pre– and post–lumbar SMT intervention.

The athletes stood with each foot on a force platform. The pre-test comprised three consecutive tasks: static standing position, held for 10 seconds; free squat, 3 repetitions; and CMJ, 3 repetitions. After the pre-test, the participants received the therapeutic lumbar SMT. After the SMT, they performed the post-test, which comprised the same tasks as the pretest performed in the same sequence.

Data were recorded before (initial) and after (final) the lumbar SMT intervention, with 5 minutes between each instance. The mean (M) and standard deviation (SD) of GRF (N/kg) calculated by the SI% before and after the SMT intervention were determined for each one individually and for all participants.

Biomechanical assessments

A motion capture system equipped with an optoelectronic system of 15 cameras at 179 Hz and two *Kistler force platforms (Winterthur, Switzerland),* operating at 500 Hz, were used to collect the biomechanical parameters.

A total set of 49 reflective markers and 5 clusters were used during the data collection based on the calibrated anatomical system technique (CAST),[75,76].

The biomechanical model was created for use in static, dynamic, and explosive actions. In addition, the symmetry index (SI%) was used. The data were captured, processed, and analyzed using *Qualisys QTM software (Gothenburg, Sweden)* and *Visual3D software (version 5.01.18, C-Motion, Inc., Germantown, PA, USA).*

Symmetry index (SI%)

The SI%[77] is the method most commonly used in physical performance tests and most cited in publications reporting on bilateral asymmetries.[6,7,78]

Symmetry measurement is the difference between two sides, known as SI, where XR is the measurement from the right side and XL is the homologous measurement from the left side (Eq. 1).

$$SI = \frac{XR - XL}{\frac{1}{2}(XR + XL)} \cdot 100\% \qquad \text{(Eq. 1)}$$

An SI% of 0% represents perfect symmetry and indicates a more symmetrical pattern; an SI of 100% represents complete asymmetry and was used to assess differences in bilateral symmetry. [6,20]

Intervention

The study intervention SMT was performed by a researcher who was also a physiotherapist and a chiropractic doctor with more than 15 years of experience in clinical and sportive physical rehabilitation.

Lumbar SMT was performed by a doctor of chiropractic using a specific type of manual SMT, the diversified technique, which aims to correct the dysfunctional lumbar vertebral segments[79] identified in the chiropractic assessments prior to the intervention. Thus, the athletes were instructed to lay prone for the spinal motion palpation analysis[80] to evaluate the presence of dysfunction (asymptomatic)[5,81] in the lumbar spine. The SMT was subsequently performed with the athlete lying sideways while a correction was performed, contacting the lumbar, namely, the transverse process (mammillary) of the lumbar vertebrae, and performing the lumbar roll technique, described by Liekens-Gillet and Bergmann[53].

Statistical analysis

The statistical analyses were performed using *SPSS (version 24; IBM, IL)* and *Matlab software (MathWorks, Inc., USA).*

The mean (M) and standard deviation (SD) of the selected variables were calculated for descriptive statistics. Kolmogorov-Smirnov tests were used to assess normal distribution. Student's t-test was used to test for significant differences between the two directions. The intra-session comparison of outcomes over time was analyzed, and the differences between pre and post instances of therapy were computed. The alpha level of significance was set at $P \leq 0.05$, and the effect sizes were defined according to Cohen as follows: small effect = 0.1, medium effect = 0.2, and large effect is considered, more than 0.5. For all analyses, $P < 0.05$ was considered statistically significant.

Results

The acceptability to participants of the treatments were total. All selected participants completed the study, and none of them reported complaints during participation.

Participants' baseline characteristics

Based on the patients' baseline anthropometric characteristics, data were calculated, and the (M) and (SD) were as follows: age, 23,4 ± 4.4; body mass, 66.5 ± 9.5; and height, 1.70 ± 0.06, respectively.

Based on previous symmetry sample characteristics, the asymptomatic athlete participants had similar asymmetry values according to the literature.

Physical performance tests symmetry outcomes measures

Static position (standing posture): The outcome measures related to the SI% were calculated considering $P < 0.05$ and an effect size of 0.35. The outcome measures, in terms of the M and SD of the SI%, were 14.4% (10) pre-intervention and 3.8% (3.1) post-intervention. There were statistically significant differences in static symmetry immediately after lumbar SMT.

Free squat: The outcome measures were presented as the M and SD of the SI% and were calculated using $P < 0.05$ and an effect size of 0.44. The M and SD were calculated pre- and post-intervention. The pre-intervention measure was 8.7% (5.2), and the post-intervention measure was 8.6% (7.1). There were no statistically significant differences in symmetry on the squat test.

CMJ: The outcomes are presented as the M and SD of the SI% and were calculated using $P < 0.05$ and an effect size of 0.35. The M and SD were calculated pre- and post-intervention. The pre-intervention value was 10.5% (7.5), and the post-intervention value was 10% (9.4). There were no statistically significant differences in symmetry after the CMJ. The symmetry outcome measures from all physical performance tests is presented in table 1.

Statistical and effect size calculations.

		Pre (N=13)			Post (N=13)			p (<0.05)	Effect Size
		Mean	(SD)	[min-max]	Mean	(SD)	[min-max]		
Static Trial	Left Limb (N)	306,5	47,0	209,0-373,0	317,3	36,0	240,0-368,0	0,72	0,05
	Right Limb (N)	302,1	51,8	222,0–378,0	307,0	38,0	239,0-364,0	0,96	-0,03
	Symmetry (%)	14,4	10,0	1,9-31,1	3,8	3,1	0,3-8,9	**0,00***	**0,35**
Free Squat	Left Limb (N)	344,8	50,5	246,0-431,0	345,2	50,1	248,0-427,0	0,99	-0,01
	Right Limb (N)	335,2	40,0	245,0-399,0	340,0	48,5	249,0-400,0	0,44	-0,11
	Symmetry (%)	8,7	5,2	0,3-20,79	8,6	7,1	0,5-28,13	0,44	0,08
CMJ	Left Limb (N)	641,2	115,9	473,0-912,0	634,4	119,1	452,0-950,0	0,73	0,05
	Right Limb (N)	629,4	139,9	356,0-889,0	633,7	142,5	368,0-917,0	0,94	-0,03
	Symmetry (%)	10,5	7,5	0,33-40	10,0	9,4	0-35,2	0,35	0,35

Table 1 - The Mean (M), standard deviation (SD) and range (minimal and maximal) of the of GRF (N) and total mean (%) symmetry, performed were calculated and analyzed effect size and statistics pre-to-post differences (P<0.05).

Discussion

Due to the absence of evidence in the literature related to the feasibility of a study to measure changes in symmetry after lumbar SMT, our study was unable to compare outcomes and discuss findings with other studies.

Despite this fact, all measured outcomes are discussed in the following sections.

Summary of findings

Based on sample characteristics, the asymptomatic athlete participants presented initially asymmetry values, similar to those previously described in the literature. [7,27,77]

Before the intervention, the participants presented a mean asymmetry value of 14.4%, indicating that some participants presented bilateral asymmetry in static position and after the SMT intervention, these values reduced significantly to what several authors considered to be the minimum level of asymmetry; for example, Herzog et al[77]reported asymmetry values ranging from 4% to 13%.

Lumbar SMT changes static symmetry, but not in dynamic actions, such as squat and CMJ. This study demonstrated the feasibility to measure the immediate changes produced by lumbar SMT in symmetry. Thus, we determined that is feasible to carry on the main study because the objectives of this preliminary feasibility study was fulfilled for conducting a large study.

Strength and limitations

This study is the first to measure physical performance test symmetry before and after lumbar SMT, to determine whether correcting lumbar spinal biomechanical dysfunction changes athletes' bilateral symmetry.

In our study, the physical performance tests symmetry result, can only be attributed to the fact that athletes responded biomechanically (only ground reaction forces (GRF) symmetry was measured) to SMT due to the effect of the manipulation on the lumbar joints and surrounding anatomical structures.[9,77,82,83] Thus, our findings therefore support that lumbar SMT changes static symmetry, through mechanisms suggested by Herzog[77,82,83]and Pickar.[84]

Therefore, our study indicates that lumbar SMT among asymptomatic athletes may have a small impact on physical performance. Unfortunately, to increase the relevance of the findings for physical and sportive performance, other variables not addressed in this present study require evaluation.

However, our findings are generalizable only to those subjects who had improved bilateral symmetry on static position tests after lumbar SMT.

The main limitations of this preliminary study are the small sample size and nonrandomized design. In addition, there was no literature support relative to the comparison of outcomes between different groups of participants.

Another limitation was related with specific biomechanical parameters of posture control measurements, namely, center of mass (COM) and center of pressure (COP), that were not analyzed because these variables were incompatible with our protocol; in our study, athlete participants wore running shoes for all procedures, and these parameters cannot be properly measured under such conditions.

Finally, another important limitation was related to listings associated with the lumbar dysfunction identified with the motion palpation and also the prevalence of lumbar segmental dysfunctions between participants. In this study, we're not performed due incompatibility of protocol, but, we recognized the importance for SMT further studies.

Future studies

This study adds information regarding the influence of the SMT intervention on symmetry and demonstrates feasibility of the measurements relative to immediate changes produced by lumbar SMT in static symmetry, but not in dynamic actions.

Future randomized controlled studies should be conducted that incorporate more variables, have two or more comparison groups, and use short-term follow-up to verify the effects over the time.

Conclusions

The results of this preliminary investigation showed that statistical significant differences were found in lumbar SMT, only for static position symmetry for this group of asymptomatic athletes' participants.

A great increase in bilateral symmetry percentage on static position was seen, but none in dynamic tests; which deserves further investigations to address our study limitations.

This study demonstrated the feasibility to measure the immediate changes produced by lumbar SMT in symmetry. However, this preliminary feasibility study demonstrated that a larger study to measure if lumbar SMT changes symmetry is feasible.

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Study 2

Intra-rater and Test-retest Reliability of Physical Performance Tests Symmetry between Lumbar Spinal Manipulation in Asymptomatic Athletes

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3

Abstract

Study Design: An intra-rater, and test-retest reliability study was performed.

Objectives: The aims of this present study was to assess the intra-rater and test-retest reliability of physical performance tests symmetry between lumbar spinal manipulation in asymptomatic athletes.

Background: In clinical and sports-related contexts, the assess of reliability and measurements errors from observers and biomechanical instruments in physical performance tests between therapeutic interventions are essential for establishment of protocols of rehabilitation programs in terms of symmetry.

Methods and Measures: Twenty athletes' performed symmetry tests (static, squat and CMJ) twice (pre and post) between lumbar intervention. The intra-rater, and test-retest reliability of physical performance tests symmetry was assessed by relative and absolute reliability on statistical calculations, with 95% confidence intervals.

Results: Kinetic symmetry presented good to excellent relative reliability by intra-class correlation coefficient (ICC´s .71 to .92). Kinematic symmetry presented acceptable to excellent relative reliability, (ICC´s .61 to .93). Lower scores of standard error of measurements, and also lower scores of minimal detectible changes were observed in both symmetry measurements (kinetic and kinematic). The limits of agreement between ratings participants' measurements indicated 62% of proportion of agreement.

Conclusions: Acceptable values of relative and absolute reliability were found by the observer on test-retest symmetry measurements in athletes. Physical performed tests symmetry demonstrated to be reliable method to measure symmetry in asymptomatic athletes, but further reliability studies are needed to address the study limitations.

Key Words

Intra-class correlation, musculoskeletal assessments, symmetry index, spinal manipulative therapy, standard error of measurement

Introduction

In clinical and sports-related contexts, the assess of reliability and measurements errors from observers and biomechanical instruments in physical performance tests between therapeutic interventions are essential for establishment of protocols of rehabilitation programs in terms of symmetry [1]–[4]

Physical performance tests in static, dynamic and explosive actions use a quantitative description of normal and abnormal symmetry parameters and are associated with physical and sportive performance [5]. In static and dynamic symmetry of physical tests [4], [6]–[9], several studies has been utilized this with high performance athletes in several performance tests and have demonstrated good to excellent reliability [4], [10]–[12].

Therefore, these studies reinforce the use of statistical strategy to assess reliability of physical performance tests in terms of symmetry. For these strategies, statistical analysis of the data is both important to assess and evaluate the measured outcomes from symmetry tests between interventions and to consistently may confirm the reliability/reproducibility, measurements error and minimal changes detected in the study variables [2],[13].

Many studies have made comparisons between symptomatic and asymptomatic individuals relative to asymmetry patterns during physical tests, such as gait [14], [15] and vertical jumps, according to studies about interventional strategies, these tests are highly recommended when taking into account reliability, measurement errors and minimal detectible changes in symmetry measurements [4],[11]. However, one problem is that many of the instruments and measurement techniques related with physical performance tests are not completely established and have often been used without validation and strategies to resolve the potential biases [16]. In addition, studies with large detectible measurement errors and low reliability, particularly for a clinical and sportive research context, may lead to an underestimation and drown out real effects [16]. In this sense, reliability is also essential for the observer/rater, biomechanical parameters measured and instruments, because it refers to reproducibly and the consistency of precision in measurements.

Little is known about the intra-rater and test-retest reliability of physical tasks in junction of therapeutic intervention.

To the best of our knowledge, there has been no study assessing the reliability of standardized symmetry tests, as described in our protocol and its application in different contexts and populations. In this sense, the aims of this present study was to assess the reliability (absolute and relative) of physical performance tests symmetry between lumbar spinal manipulation in asymptomatic athletes' participants.

Methods

Sample Size

Based on prior sample size calculations, twenty (n:20) asymptomatic athletes' participants from different modalities and sportive levels, (11 females and 9 males), participated in this study.

According literature related, the number of participants was sufficient and viable for application in this type of study [17].

The priori t-test, one tail, with effect = .5, alpha= .05 and statistical power [19] of .8, were obtained by GPower [19] software. According to GPower [19], the effect size conventions (d = .80) stated, is considered a large effect.

Participants Recruitment and Informed Consent

The participants were recruited through public advertisements at the Centre of High Performance (CAR), University of Lisbon, Portugal, according to the eligibility process.

Ethical standards were applied according to the Helsinki Declarations, and the research protocol was approved by the Faculty of Human Kinetics (FMH), University of Lisbon; Ethics Research Committee under register number 31/2017.

This prospective study was conducted to assess the reliability of the study to measure the physical performance tests symmetry between SM intervention to the lumbar spine. Registered by ISRCTN47602572.

The CONSORT flow diagram, which is highly recommended for clinical trials studies [20] , was used as described in figure 1, which spans the time from enrolment, allocation, and data collection procedures through the analysis of the data gathered from all volunteers' participants in this study.

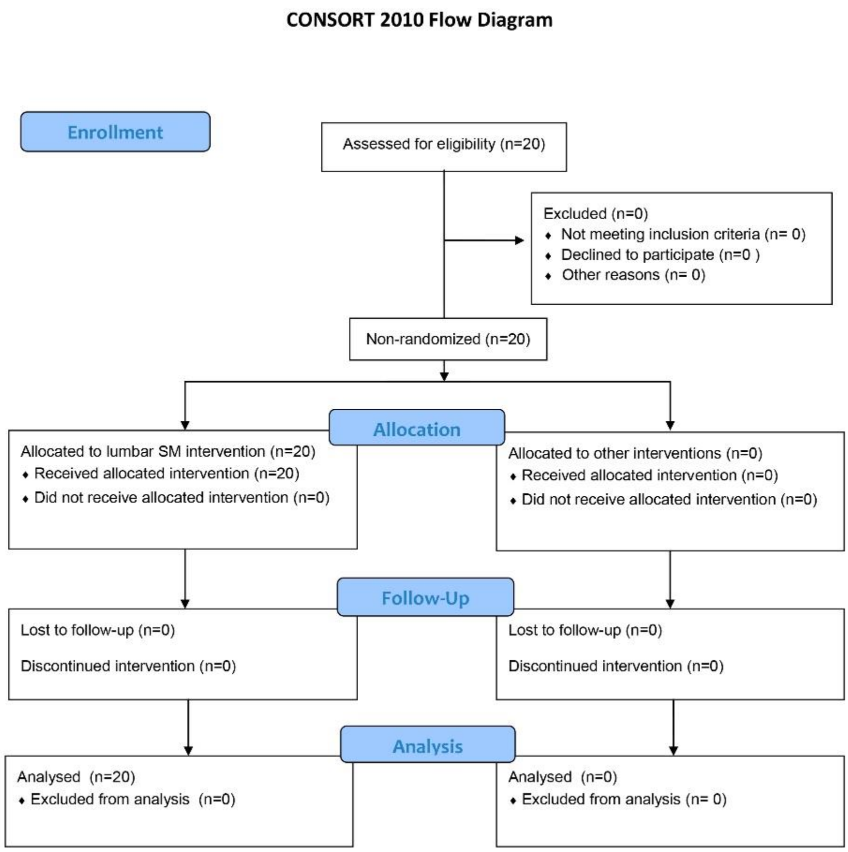

Figure 1 – The CONSORT flow-chat diagram.

All participants were informed of the procedures and risks of the study and signed an informed consent prior to their enrolment in the study. All participants completed the study, and, the rights were protected, and none of them reported complains during the participation.

Eligibility Criteria

All selected participants were asked to fulfil the eligibility criteria. Athletes were required to undergo a physical evaluations [21]–[25], which was administered at the biomechanics laboratory, to ensure that the participants complied with the eligibility criteria.

The participants were athletes of any gender, aged between 18 and 35 years old, and were asymptomatic and had a normal clinical evaluation [24], [26]–[29]. Participants who experienced any changes in their training routine or competition during the study, participants who had a history of lumbar and/or lower limbs surgery, and who were treated with manual therapy at any time during the study were excluded [27], [28].

Biomechanics Assessments

The specific biomechanical model was created to help exchange information about the kinetic and kinematic symmetry parameters [30]. The three-dimensional model consisted of 8 independent rigid segments in the trunk, pelvis, thighs, shanks and feet.

The marker set-up and biomechanical 3D model were illustrated on figure 2. The anterior (left) and posterior (right) views of the markers placement, and rigid clusters (squares with 4 markers) were placed on the lateral aspect of the thighs and shanks. A total set of 49 reflective markers and 5 clusters, such as presented on figure 2, were used during the data collection in the biomechanics laboratory, based on the calibrations technique [14], [31]–[33].

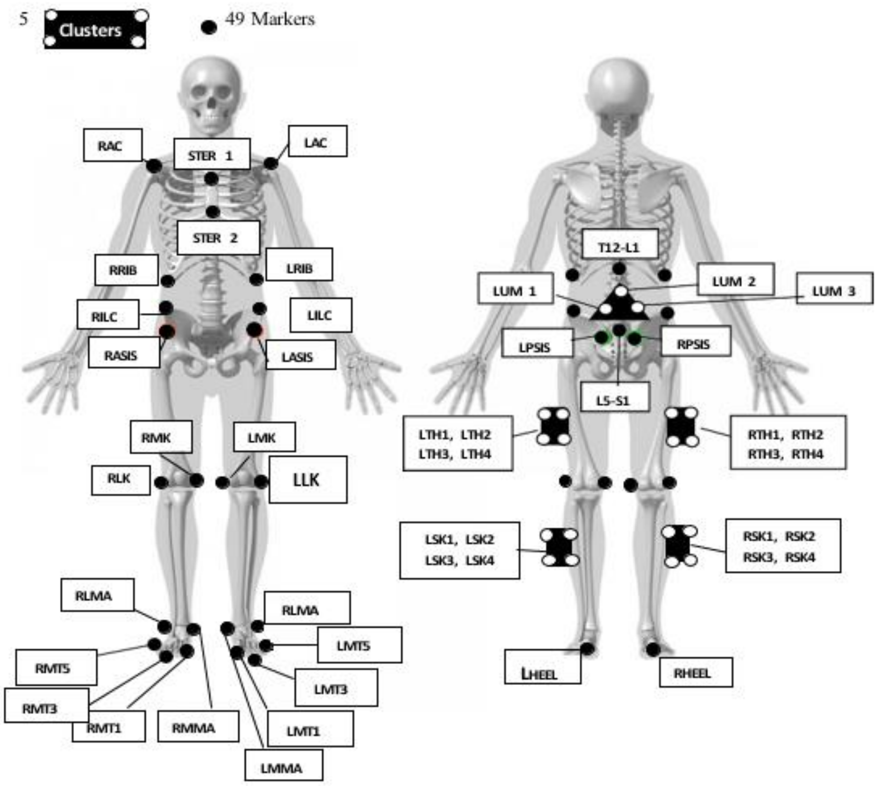

Figure 2 – Marker set-up and biomechanical 3D model.

All data processing and model building were performed using Qualisys (Software – C-motion, Göteborg, Sweden), integrated with Visual 3D software - Version 5.01.18, C-Motion, Inc., Germantown, USA).

Two force platforms (left and right), and under motion capture system equipped with an optoelectronic system of 15 cameras at 240 Hz, participants were placed at or around the centre of the participant's body while standing to perform tests. For static and motion capture, the marker trajectories were utilized integrating the software's, with butterworth low-pass filter, with cut-off frequency of 10 Hz.

Study Protocol

This study consisted of a single session of data collection capture with each of the 20 asymptomatic individuals who performed test-retest physical performance tests (static posture, free squat and countermovement jump) before and after lumbar SM.

The participants received 5 min of task training, and performed physical tests before and after lumbar SM intervention. The pre and-post-phases were conducted in approximately 5 min between tests.

Physical Performance Tests Sequence

The physical performance tests symmetry sequence, before and after Lumbar SM intervention, were illustrated on figure 3.

Each participant performed repeated 14 trials of pre- and post-physical performance tests symmetry (2 static positions, 6 free squats and 6 countermovement jump, CMJ), with an interval of 5 minutes between the lumbar SM intervention, for a total of 280 trials. The same rater and same instructions were given before the start of the tests and all of the participants had a sufficient amount of time to ask questions.

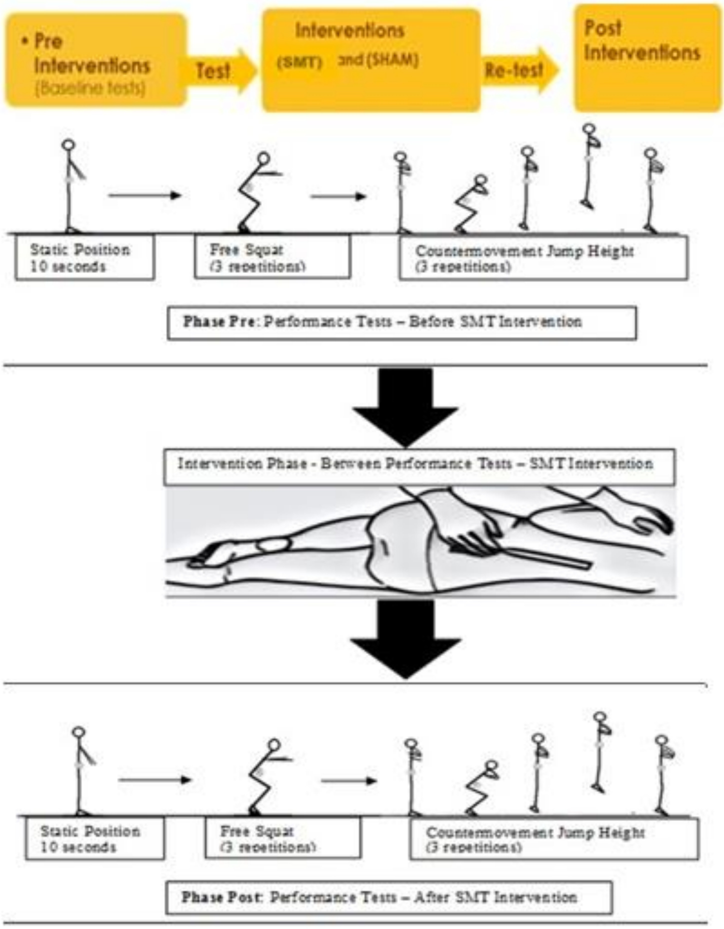

Figure 3 – Physical performance tests sequence.

Intervention

The study protocol and intervention SM were performed by a researcher; physiotherapist doctor with more than 15 years of experience in clinical and sportive physical rehabilitation.

Spinal Manipulation (SM)

Spinal manipulation is recognized as a safe and effective therapy for musculoskeletal disorders that has been increasingly used in sports and has been useful therapeutic strategy for biomechanical joint dysfunction, especially that involving the spine. SM is commonly practiced by physiotherapy, chiropractic, and orthopedic doctors to correct biomechanical dysfunction of spinal joints.

This technique uses high-velocity, low-amplitude movement applied at the paraphysiological space, beyond the passive joint range of motion.

The lumbar SM was performed by a doctor on the athletes' participants using specific type of manual SM, the Diversified technique, that aim to correct the lumbar vertebral dysfunctional segments [24], [25], [34]–[36] identified in the clinical assessments prior to the intervention.

Thus, the athletes were instructed to lay down prone for the spinal motion palpation analysis [36], to evaluate the presence of biomechanics dysfunction in the lumbar spine. The SM was subsequently performed with the athlete laying sideways while a correction was performed contacting the lumbar, namely on transverse process (mammillary) of the lumbar vertebrae, performing the lumbar roll technique, described by Liekens-Gillet and Bergmann [25].

Symmetry Measured Outcomes

For the purpose of this study, the kinetic symmetry was called symmetry 1, and kinematic symmetry was called symmetry 2, for easy comprehension. According to the biomechanical literature, this is a good representation that has been elaborated based on symmetry 1 (force efforts between the lower limbs; ground reaction forces during physical performance tests) and symmetry 2 (segmental organization of the whole body during all cycles of physical performance tests, and body orientations relative to connections of joint centre vectors displacements).

Symmetry 1 (symmetry index calculations)

The kinetic parameters are commonly measured in physical performance tests [4], [5], [37] in static and dynamic tasks [38]–[42], through of ground reaction forces (GRF), (N/kg) [43] on symmetry calculations.

Symmetry 2 (Linear global symmetry Index calculations)

The kinematic parameters was calculated through linear global symmetry index (LGSI) adapted from the Global Gait Asymmetry Index (GGA) [14] for calculations of symmetry during all cycles of physical performance tests.

Statistical Protocol

The intra-rater, intra-session, test-retest reliability of physical performance symmetry measurements was integrated for an in-depth statistical analysis to provide consistency of the measured outcomes.

Using SPSS software (Version 24: IBM, Chicago, IL), the normal distribution [51] of data was calculated using the Kolmogorov–Smirnov test. The presence or absence of heteroscedasticity was primarily confirmed by Bland–Altman protocol [52] with magnitude of the mean correlating with the absolute difference from test-retest [1]. Secondly, the heteroscedasticity and homoscedasticity of the data were identified, and a normal distribution was ensured in order to avoid carry-over effects between repeated tests.

ANOVA was conducted; a two-way random model, absolute agreement and consistency were evaluating for relative and absolute reliability. Also, Microsoft Excel Software was used to analyses of all remaining data.

Reliability Assessments

To easily comprehend our statistical reliability implemented in our study, two variations of test-retest reliability evaluations were performed, including, intra-rater (relative reliability), and test-retest (absolute reliability).

Reliability can be express as relative and absolute reliability. Relative reliability is obtained by calculating the intra-class correlation coefficient (ICC), which indicates to what extent repeated measurements will reveal consistent individuals' scores by the rater within a group of participants [45]. The relative reliability was calculated through SPSS software; a two-way random effects model, and was expressed as ICC 95% (CI) for intra-rater reliability [46], for evaluation of the random errors, that may affect the relative test–retest [1] intra-session.

Absolute reliability was determined by the standard error of measurement (SEM), which indicates the variability in scores upon repeated testing [1]. SEM, a reliability statistic that quantifies the measurement error in the same units as the original measurement [47], was included and calculated as described in equation 1.

$$\mathrm{SEM} = \mathrm{SD}\sqrt{(1 - ICC)} \qquad \text{(eq.1)}$$

Several researchers also agreed with the use of SEM to differentiate between individual real changes and those due to measurement error [48].

Thus, Integrating the intra-individual and total standard deviation on the physical performance tests were also calculated with 95% CI for standard deviation of differences (SDdiff).

The absolute agreement reliability with 95%(CI) are commonly used to investigate different sources of individual variation or measurement error variance intra-session tests by Bland–Altman protocol, to estimate the agreement between ratings, magnitude of bias and the possibility of error varying according symmetry scores being measured.

Agreement is also presented as a percentage of the mean score, with 95% of the limits of agreement (LOA), lower and upper limits, were described below on equations 2 and 3, respectively. The mean is the mean for all of the measures for the test and retest.

Lower Limit 95% CI = mean – (SD x 1.96) (eq.2)

Upper Limit 95% CI = (SD x1.96 + mean) (eq.3)

The 95% limits of agreement were calculated as the mean difference ±1.96 SD of the differences. The limits were analysed by the means of the proportion of agreement between two assessments periods (pre and post) of physical performance tests symmetry (between lumbar SM).

The MDC is interpreted as the smallest amount of change required to designate a change as real and beyond the bounds of measurement error [50]. Thus, the MDC representing the magnitude of change necessary to exceed the measurement error of two repeated measures at a specified confidence interval. This refers to the minimal amount of change outside of error that reflects a true change, which is better than a variation in measurements by the study participants. It was calculated by applying the equation bellow, with 95% CI, as a 1.96 is the two-sided tabled z value for the 95% CI, and $\sqrt{2}$ is used to account for the variance of two measurements equation 4.

$$MDC = SEM \times 1.96 \times \sqrt{2} \qquad \text{(eq.4)}$$

Results

The relative and absolute reliability of physical performance tests symmetry were assessed by ICCs, SEM, SEMdiff, LOA, and MDC, and the results were presented in table 1 and table 2.

Relative Reliability

Statistical reliability with ICCs 95% of confidence interval were assessed for intra-rater, test-retest physical performance tests symmetry. ICC relative reliability varied from acceptable to excellent (ICC = .61 – .93) in both symmetry measurements.

Highest ICCs were found for the static trials (ICC = .92) and countermovement jump (ICC= .93) of kinetic and kinematic symmetry measurements, respectively. Good to excellent ICCs were also found in 90% of symmetry variables (ICC = .71 – .93).

Measurements from symmetry 2 presented acceptable reliability for physical performance test-retests measured outcomes, with ICCs greater than (.60) while the remaining, showed acceptable to good (ICC ≥ .61 to .70).

Absolute Reliability

Absolute reliability statistics 95% CI, were obtained for intra-session agreement. Kinetic symmetry (1) exhibited lower SEMs scores from test-retest (static, squat and CMJ) of (3.0), (3.1) to (4.3), respectively, indicating low levels of errors during tests. Kinematic symmetry (2) also exhibited lower SEMs scores from test-retest ranging from (.1 to .3).

The SEM differences at 95%CI ranged from (.24) to (8.62). In total sample, pre and post trials, SEM ranged from (.12 – 4.3%) for the kinetic and kinematic symmetry intra-session.

The SEM% varying of 12% was low for all variables (less than 5%). In 100% of the variables, a SEM% 5% was obtained. A higher number of variables below a threshold (SEM% 5%) in the intra-rater were (95%).

The limits of agreement (LOA) results indicated a 62% proportion of agreement of the pre- and-posts differences between ratings and measurements on participants; that was expected 95% of confidence interval, varying between (.5 – 39%) with range of 38%.

Relative to MDC, lowers scores were found in 90% of the all symmetry measurements; less than 10 points.

Kinetic Symmetry (1) Reliability	ICC (95% CI)	Pre Post Diff	SEM	LOA (95% CI) Lower–Upper Limits	SEM diff	MDC
Static position	0.92 (0.82-0.97)	12.5	3.08	(12.5 –32.5)	6.16	8.5
Squat	0.77 (0.41-0.90)	-0.9	3.10	(2.9 – 22.5)	6.22	8.7
CMJ	0.71 (0.26-0.88)	-0.6	4.31	(2.7 – 28.7)	8.62	9.1

Table 1 - Kinetic Symmetry: Intra-rater, intra-session, test-retest reliability statistics (ICCs), limit of agreement (LOA), the measured standard error (SEM), and minimal changes detectable (MDC).

Abbreviations**:** AB1: ICC, intra-class correlation coefficient; AB2: SEM, standard error of measurement; AB3: LOA, limit of agreement; AB4: SEMdiff, standard error of differences; AB5: MDC, minimal detectible changes; AB6: CMJ, countermovement jump; AB7: CI, confidence interval.

Kinematic Symmetry (2) Reliability	ICC (95% CI)	Pre Post Diff	SEM	LOA (95% CI) lower-upper Limits	SEM diff	MDC
Static Position	0.78 (0.46 – 0.91)	0.081	0.20	(-0.59 – 2,3)	0.40	3.8
Squat	0.61 (0.005 –0.84)	0.04	0.28	(0.94 – 2.7)	0.56	4.2
CMJ	0.93 (0.76 – 0.97)	0.13	0.12	(-0.9 – 2.8)	0.24	1.7

Table 2 - Kinematic Symmetry: Intra-rater, intra-session, test-retest reliability statistics (ICCs), limit of agreement (LOA), the measured standard error (SEM), and minimal changes detectable (MDC).

Abbreviations**:** AB1: ICC, intra-class correlation coefficient; AB2: SEM, standard error of measurement; AB3: LOA, limit of agreement; AB4: SEMdiff, standard error of differences; AB5: MDC, minimal detectible changes; AB6: CMJ, countermovement jump; AB7: CI, confidence interval.

Discussion

Assessing intra-rater and test-retest reliability, our study presented acceptable to excellent relative reliability, and acceptable absolute reliability scores, confirming the safety and accuracy of physical performance tests symmetry measurements.

Both symmetry measurements presented ICC varying from acceptable to excellent relative reliability (ICC = .61 – .93). According literature, the reliability of the raters [12], instruments[1] and performance tests, ICCs values= .41 to .96 indicated small to large reliability; an ICC of 0.70 indicated good reliability, an ICCs higher than (.90) indicated excellent reliability [1], [53], [54], particularly for sportive and clinical measurements, with symptomatic participants and their health conditions [1], [53], [55].

The absolute reliability describes the within-subject variability attributable to evaluations of repeated measures intra-session. This established statistical method is commonly used in sports medicine and physical therapy [1], [42], [56], [57].

To interpret SEM, is necessary take account normal distribution, because of the errors are normally distributed around zero and is expect the average of errors to be zero [51], [58]. Payne et al [59], suggested that the use of the SEM serves to verify if there is present heteroscedasticity, which is commonly assessed in sports-related studies [1]. In this way, considering that homoscedasticity is uncommon in ratio variables, as symmetry relevant to sports medicine, in our study, the SEM scores from kinetic and kinematic symmetries, showed approximately at least half values to the mean (M) and standard deviation (SD) of test-retest performance tasks, repeated measurements.

In our study, symmetry measurements exhibited lower SEMs scores from test-retest intra-session, ranging from (.1 to 4.3). Thomas and Nelson [60], reported that an immediate retest performed in one session reflects the internal consistency, and its results referring to reliability are higher than in the case of the inter-session retest.

Several researchers also agreed with the use of SEM to differentiate between the individual real changes and those due to measurement error [48]. In addition, also absolute agreement reliability with 95% CI are commonly used to investigate different sources of individual variation or measurement error variance intra-session tests.

To obtain an agreement and good reliability of the analysed variables aggregate in both contexts are very important.

In addition, the smallest within-subject change that could be interpreted as a real change.

Acceptable values of the reliability for this measure, typically are 60% for proportion of agreement that coefficient that adjust the reliability estimate for chance agreement (.50) to (.80) for the coefficient and ($p < .05$) for the tests in association between the pre and post-tests. However, in our study, the limits of agreement indicated a 62% proportion of agreement of the pre and posts differences between ratings and measurements on participants that was expected 95% of the kinetic and kinematic symmetry 1 and 2.

Thus, the difference of the same rater performing intra-session test-retest physical performance tests in athletes were assessed, and the agreement between the test and retest intra-session, were confirmed by the limits of the selected variables. The confidence interval, varying between (.5 – 39%), with range of 38%, and is known as the limit of disagreement.

Relative to MDC is well known that the variation is dependent on the specific variable [30], and in our study, 90% of the majority of symmetry variables on physical tests, presented lower MDC values of less than 10 points, suggesting that the effects of these calculations improved the confidence of the symmetry measured outcomes.

Consistent with clinical and sportive investigations with 95% of confidence intervals, were conducted statistical calculations to assess the intra-rater and test-retest reliability of physical performance tests symmetry, and our results indicated safety, accuracy and internal consistence of symmetry measurements. According literature, one session of data collection reflects the internal consistency, and its results referring to reliability are higher than in the case of the inter-session retest.

The main limitation of this study was due the fact that in our study were not performed inter-rater and inter-session analysis of reliability, because was incompatible with our protocol.

Another important limitation was related to small sample size. Future studies with a large sample size, and with different populations are needed to address the study limitation.

Conclusions

Acceptable values of relative and absolute reliability were found by the observer on test-retest measurements in athletes. The physical performed tests symmetry demonstrated to be reliable method to measure symmetry in asymptomatic athletes.

Therefore, this intra-rater and test-retest reliability study confirms the safety, accuracy and reproducibility of the symmetry measurements.

Thus, we suggested the use of the physical performance tests symmetry in future studies to reliably measure the symmetry in asymptomatic athletes. Nevertheless, further reliability studies are needed to address the study limitation.

Key Points

Findings: Acceptable to excellent scores of relative reliability and acceptable scores of absolute reliability were found in this intra-observer and test-retest physical performance tests symmetry.

Kinetic symmetry presented good to excellent relative reliability by intra-class correlation coefficient (ICC´s .71 to .92). Kinematic symmetry presented acceptable scores of relative reliability, (ICC´s .61 to .93).

Lower scores of SEM were observed, indicating low levels of errors during symmetry tests. The LOA of 62% indicated the proportion of agreement between ratings of participants' measurements, and the MDC was small in 90% of symmetry measurements.

Implications: Consistent with clinical and sportive investigations with 95% of confidence intervals, our reliability study demonstrated safety, accuracy and reproducibility of symmetry measurements. However, the physical performance tests seem to be a reliable method to measure symmetry by the rater, during intra-session and test- retest.

Caution: The main limitation of this study was due the fact that in our study were not performed inter-rater and inter-session analysis of reliability, because was incompatible with our protocol. Another limitation was related to small sample size.

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Study 3

The effects of a single-session of lumbar Spinal Manipulative Therapy (SMT) in terms of physical performance tests symmetry in asymptomatic athletes: a single-blinded, randomized controlled study

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Abstract

Background/Aim: Musculoskeletal disorders in athletes, including spinal biomechanical dysfunctions, are believed to negatively influence symmetry. Spinal manipulative therapy (SMT) is recognized as a safe and effective for musculoskeletal disorders, but still little evidence if can be beneficial in symmetry. Therefore, this study aimed to measure the effects of lumbar SMT in symmetry.

Methods: Forty asymptomatic athletes' participants were included in this study. The randomization procedure was performed to groups allocation, group 1(SMT) and group 2(SHAM). Each participant underwent a physical activity questionnaire, and, also clinical and physical evaluation for inclusion according eligibility criteria. Statistical significance ($P < 0.05$) between groups and instants of therapy were calculated by physical performance tests symmetry (static position, squat and CMJ), Pre-and-Post SMT and SHAM. There were 14 trials of 3 symmetry tests for each participant, totalizing 560 trials.

Results: Lumbar SMT produced immediate effects in symmetry on static; however, the same effects were not found in squat and CMJ, on symmetry 1. Therefore, our results showed a significant difference in pre (mean:16.3%) and post-lumbar SMT (mean:3.7%) in static symmetry. However, the symmetry 2 showed no statistical significant differences for any of tests and intervention groups. No statistical significant effects in symmetry pre-to-post SHAM, were found in any of the tests.

Conclusions: Statistical significant differences were found in lumbar SMT, only for static symmetry. These findings suggest that SMT was effective to produce immediate effects in symmetry on static position, but none in dynamic tests. Future studies could to address our study limitations.

Keywords: biomechanics phenomena, musculoskeletal disorders, lumbar spine, bilateral asymmetry, symmetry index.

Introduction

Musculoskeletal disorders in athletes, including spinal biomechanical dysfunctions(1–4), which are often asymptomatic, are believed to negatively influence physical performance in terms of symmetry(5–11).

Asymmetric athletes may thus show decreased physical performance or have an increased risk for injury as a result of favouring the bilateral asymmetry of the body(12,13). Tomkinson, et al(12,14) suggested that athletes who are symmetric also have improved physical performance.

Bilateral asymmetry has been shown to be indicative of spinal abnormalities(7,15), and, in clinical and sportive contexts, the ability to detect abnormal biomechanical parameters is extremely important, when focusing on restoring normal function through the treatment strategies of these abnormalities(16–19). In this sense, we hypothesize that a therapeutic strategy for correcting spinal biomechanical dysfunctions through a lumbar spinal manipulative therapy (SMT) intervention, could produce immediate effects on symmetry.

SMT is a safe and effective therapy for musculoskeletal disorders that has been increasingly utilized in sports(20–23). SMT purpose is to correct spinal joints biomechanical dysfunctions using a high-velocity, low-amplitude movement, applied at the paraphysiological space, beyond the passive joint range of motion(21,24–26).

A recent systematic review of the literature(20), showed several studies that associate SMT with sportive performance, but none of them have been focused on physical performance test, namely in symmetry.

Nevertheless, several gaps in knowledge as well as a low level of evidence were found in the related scientific literature(4,7,20,27). Therefore, to address these gaps, this randomized controlled study aimed to quantitatively measure the immediate effects of lumbar SMT on symmetry through physical performance tests: static standing position, squat movement, and countermovement jump (CMJ) in asymptomatic athletes.

Methods

Study design

A single-blinded, single-session, randomized controlled study was conducted.

Sample size calculations

Based on prior sample size(28) calculations, forty (n:40) athletes (20 females and 20 males) of different sports, participated in this study.

According literature related, this number of participants performing multiple trials, was sufficient and viable for application for this type of study, to ensure good statistical viability with regards to the parameters in question(28,29).

Participants recruitment

The participants were recruited through public advertisements at the Centre of High Performance (CAR), University of Lisbon, Portugal, according to the triage process.

Ethical standards were applied according to the Helsinki Declarations, and the research protocol was approved by the Faculty of Human Kinetics (FMH), University of Lisbon; Ethics Research Committee.

The CONSORT flow diagram, which is highly recommended for randomized clinical trials(30), was used as described in figure 1, which spans the time from enrolment, allocation, and data collection procedures through the analysis of the data gathered from all volunteers' participants in this study.

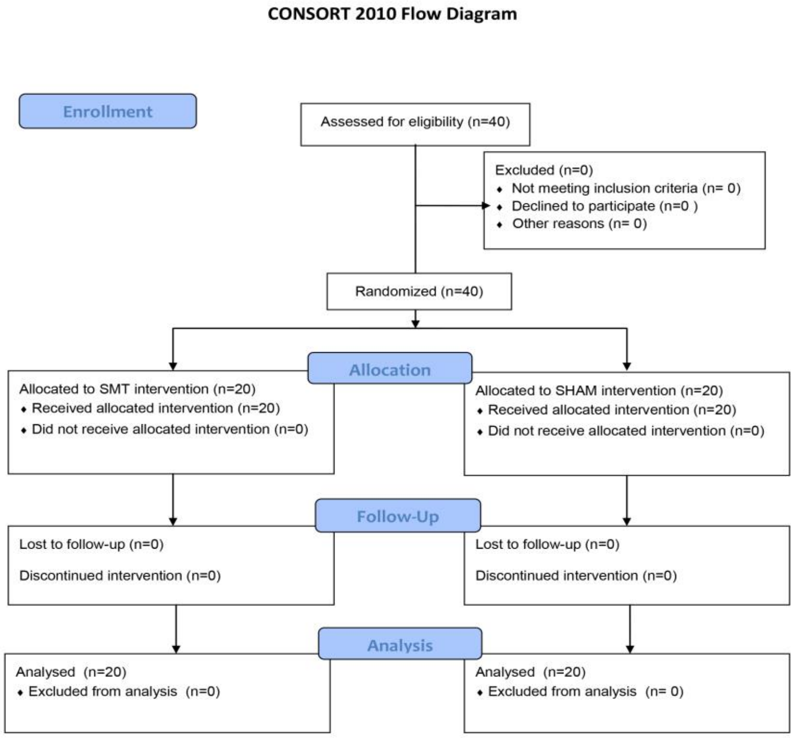

Figure 1 - CONSORT Flow-chart describing the randomized controlled study protocol.

Eligibility criteria

All selected participants were asked to fulfil the eligibility criteria.

Each participant underwent a clinical and physical evaluation, performed by one experienced physiotherapist and a chiropractic doctor, to verify suitability for inclusion. The participants were athletes of any gender, aged between 18 and 35 years old, and were asymptomatic and had a normal clinical evaluation.

The participants were required to be physically active according "International Physical Activity Questionnaire" (IPAQ),Short-form(31) scores to standardize the sample including only active participants; medium-to-high level of physical practice, to ensure homogeneity(29).

Athletes who did not have the characteristics of an active person were excluded. Participants who experienced any changes in their training routine or competition during the study, participants who had a history of spinal surgery, and who were treated with manual therapy at any time during the study were excluded(32).

Randomization procedure

After the eligibility criteria were fulfilled and the consent form was signed, participants were informed that the study protocol consisted of “therapeutic interventions” between physical tests.

The athlete participants were randomly divided into two groups by drawing from a black envelope containing group assignment. All selected participants were asked to draw out one small ticket containing either the number 1 or 2, referring to Group 1 (n = 20), those who received the lumbar SMT intervention, and Group 2 (n = 20), those who received the SHAM intervention.

Single-blinded – Intervention mask procedure

The intervention mask procedure was performed only for group assignment (SMT and SHAM interventions), thus establishing the single-blinded construct of the study(33). In fact, the participants were not made aware of whether a therapeutic intervention would reach a “mechanical effect” or whether no effect, independent of the type of interventions. Although it is reasonable to suggest that participants may notice a physical difference after intervention, participants did not know to which intervention their group was allocated; participants only knew that they received one therapeutic intervention, as was initially explained.

Biomechanical assessments

The biomechanical model(34–36) was created for use in static, dynamic and explosive actions. A total set of 49 reflective markers and 5 clusters were used during the data collection based on the calibrated anatomical system technique (CAST),(36,37).

Motion capture system equipped with an optoelectronic system of 15 cameras at 179 Hz and two *Kistler* force platforms *(Winterthur, Switzerland)*, operating at 500 Hz, were utilized to collect the biomechanical parameters. Aditionaly, two symmetry index (%) were used. The data were captured, processed and analysed using *Qualisys QTM software (Gothenburg, Sweden)* and *Visual3D software* (*Version 5.01.18, C-Motion, Inc., Germantown, USA).*

Study Protocol

Physical performance tests symmetry (static position, free squat and CMJ jump) sequence, (Pre-and-Post SMT and SHAM interventions) was presented on figure 2.

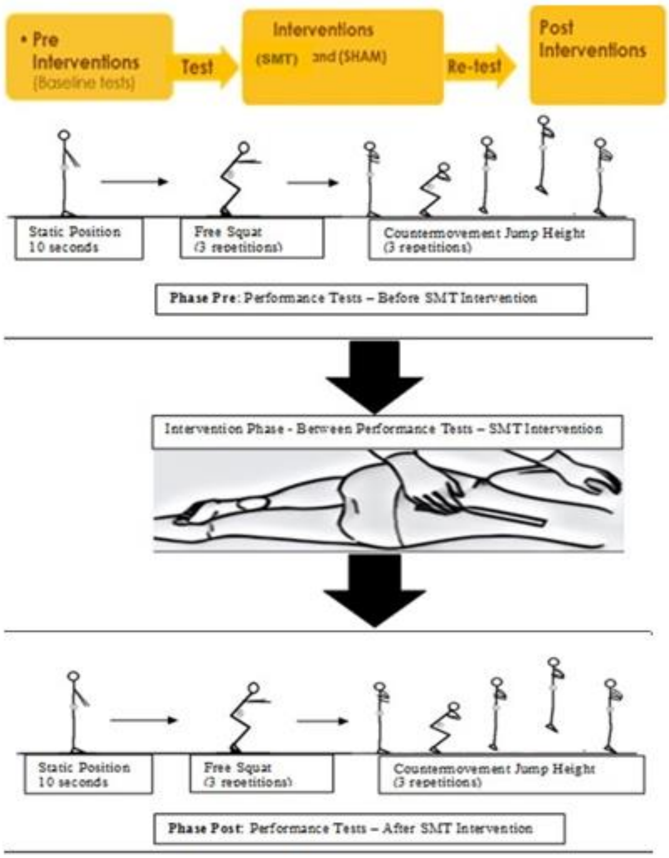

Figure 2 - Study protocol, presenting physical performance tests symmetry (static, squat and CMJ) sequence, pre and post SMT and SHAM interventions.

There were 14 trials of 3 physical performance tests symmetry (static position, squat movement and CMJ high) for each participant, totalizing 560 trials for all athletes' participants (n:40).

Interventions

The study interventions SMT and SHAM was performed by a doctor, as showed in figure 3; 3 a) and 3 b), respectively.

Spinal Manipulative Therapy (SMT)

Who only received the Lumbar (SMT). The SMT was performed by a doctor on the athletes participants using Diversified techniques(38) that aim to correct the lumbar vertebral dysfunctional segments identified in the clinical assessments prior to the intervention. The participants were instructed to lay down prone for the spinal motion palpation analysis, to evaluate the presence of dysfunction in the vertebral segments of the lumbar spine. The SMT was subsequently performed with the athlete laying sideways while a correction was performed contacting the lumbar, namely on transverse process (mammillary) of the lumbar vertebrae, performing the lumbar roll technique, described by Liekens-Gillet and Bergmann(38), as showed on figure 3a).

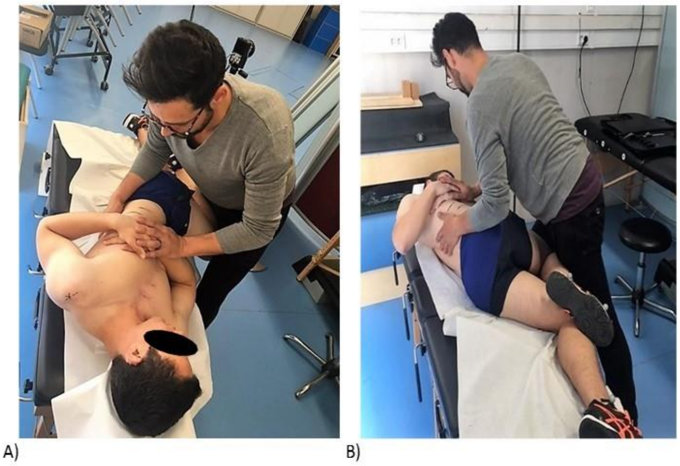

Figure 3 - a) Picture of view of the participant receiving lumbar SMT intervention; b) Picture of view of the participant receiving SHAM pre-positioning lumbar SMT intervention, performed by a researcher.

SHAM control intervention

Who only received the “SHAM” procedure (pre-load SMT positioning). The SHAM intervention was performed with the participant in the lateral recumbent position, as described in the lumbar SMT intervention. The researcher guided the participant through the same motion as that in the SMT using the maintenance of the setup position; however, no manipulative thrust was delivered. The doctor applied minimal pressure, and the position was maintained for approximately 1 minute in total for both sides, as showed on figure 3b). The SMT and SHAM interventions were both performed by a researcher; physiotherapy and a chiropractic doctor with more than 15 years of experience in clinical and sportive physical rehabilitation.

Symmetry Indexes

Symmetry 1 (Symmetry index SI %)

The SI index (%) is the method most commonly used and cited in publications to report bilateral asymmetries in physical performance tests(9).

The symmetry measurement is the difference between two sides, known as SI, where X_R is a measurement from the right side and X_L is a homologous measurement from the left side (eq.1).

$$SI = \frac{XR - XL}{\frac{1}{2}(XR + XL)} \cdot 100\% \qquad \text{(eq.1)}$$

The SI (%), expressed as a percentage, 0%, which represents perfect symmetry, indicating a more symmetrical pattern, and 100%, which represent complete asymmetry, was used to assess differences in the bilateral symmetry.

Symmetry 2 (Linear Global Symmetry Index LGSI %)

To calculate symmetry LGSI was used to measure the left and right sides in each performance test. Through this index, we were able to calculate the 3D components of the Euclidean distances from the “joint centres” to the pelvis origin, such as illustrated on figure 4.

The index was calculated as described by Cabral, S. et al(39), adapted from the LGGA (linear global gait asymmetry) index, and is indicated in the following equation:

$$\text{LGSI} = \sum_{v=v_1}^{v_{15}} \sqrt{\sum_{t=t_1}^{t_{101}} [x_l(t) - x_r(t)]^2} \quad \text{(eq. 2)}$$

The 3D components of each vector are the input **v** in this index’s equation, where **v** represents the angular variables (all three components of the hip, knee and ankle joint angles, the absolute pelvis angle, and the trunk angle in relation to the pelvis), and x**l** (t) and x**r** (t) are the values obtained for the left and right sides, respectively, at **t** (each percentage of the time-normalized performance test cycle),(40).

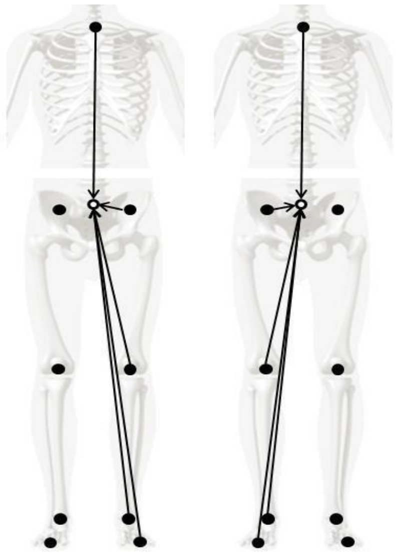

Figure 4 - Vectors for the Euclidean distances computed during the right side and during the left side, for the LGSI% calculations.

Statistical Analysis

Statistical calculations were performed using *SPSS (Version 24:IBM,IL),* and *Matlab software (MathWorks, Inc., USA).*

Kolmogorov-Smirnov tests were conducted before the statistical analysis, and they confirmed that the data were normally distributed. The significance of the differences between means of the participant characteristic groups (age, weight and height) was determined by one-tailed, unpaired Student's t-test. The mean (M), standard deviation (SD) and range (minimum and maximum) values of the selected variables were analysed. Differences between groups and pre-to-post instances of therapy were analysed using 2-way analysis of variance (ANOVA). For all analyses, ($P < 0.05$) was considered statistically significant.

Results

Baseline participants' characteristics

Based on the baseline participant characteristics, all participants were similar in relation to asymptomatic conditions, level of physical activity, and, anthropometric characteristics.

The IPAQ classification values for all participants (n:40) were calculated, and, demonstrated high level of physical activity, with a mean (M) score of 3.342 MET/kg/min and standard deviation (SD) of 233 MET/kg/min.

Participants' anthropometric data were calculated, and, presented the mean (M) and standard deviation (SD) for age of 23.8; ±5.3, body mass of 63; ± 7.5 and height of1.68; ± 0.06, respectively.

All participants completed the study, and, none of them reported complains during the participation.

Symmetry – Outcome measures

Group 1 (Lumbar SMT)

Symmetry 1

Static standing position: The pre-phase was (M) 16.30% and (SD) ± 11.43, with a post-phase of (M) 3.77% and (SD) ± 4.13. There were statistically significant differences in static symmetry (P=0.01), immediately after lumbar SMT.

Free Squat: The pre-phase was (M) 9.37% and (SD) ± 6.9, with a post-phase (M) of 10.27% and (SD) ± 7.70. There were no statistically significant differences.

Countermovement jump (CMJ) high: The pre-phase was (M) 12.8% and (SD) ± 8.6, with a post-phase (M) of 13.3% and (SD) ± 8.1. There were no statistically significant differences.

Group 1 (Lumbar SMT)

Symmetry 2

Static standing position: The pre-phase was (M) 1.48% and (SD) ± 0.48, with a post-phase measurement of (M) 1.40% and (SD) ± 0.47. There were no statistically significant differences.

Free Squat: The pre-phase was (M) 1.86% and (SD) ± 0.51, with a post-phase of (M) 1.82% and (SD) ± 0.61. There were no statistically significant differences.

Countermovement jump (CMJ): The pre-phase was (M) 1.96% and (SD) ± 0.55, with a post-phase of (M) 1.83% and (SD) ± 0.49. There were no statistically significant differences.

Group 2 (SHAM)

Symmetry 1

Static standing position: The pre-phase was (M) 10.75%, and (SD) ±10.50; with a post-phase (M) of 9.02% and (SD) ±6.18. There were no statistically significant differences.

Free Squat: The pre-phase was (M) 11.73% and (SD) ± 9.55; with a post-phase (M) of 12.45% and (SD) ± 9.57. There were no statistically significant differences.

Countermovement Jump (CMJ): The pre-phase was (M) 13.99% and (SD) ± 8.76; with a post-phase (M) of 12.40% and (SD) ± 8.59. There were no statistically significant differences.

Group 2 (SHAM)

Symmetry 2

Static standing position: The pre-phase was (M) 1.30% and (SD) ±0.40, with a post-phase (M) of 1.46% and (SD) ±0.52. There were no statistically significant differences.

Free Squat: The pre-phase was (M) 1.90% and (SD) ± 0.52, with a post-phase, (M) of 2.03% and (SD) ±0.57. There were no statistically significant differences.

Countermovement Jump (CMJ): The pre-phase was (M) 2.04% and (SD) ±0.66, with a post-phase, (M) of 1.99% and (SD) ±0.49. There were no statistically significant differences.

The symmetry 1 and symmetry 2 outcome measures from both groups (SMT and SHAM), were visually presented by box-plot diagram, on figure 5.

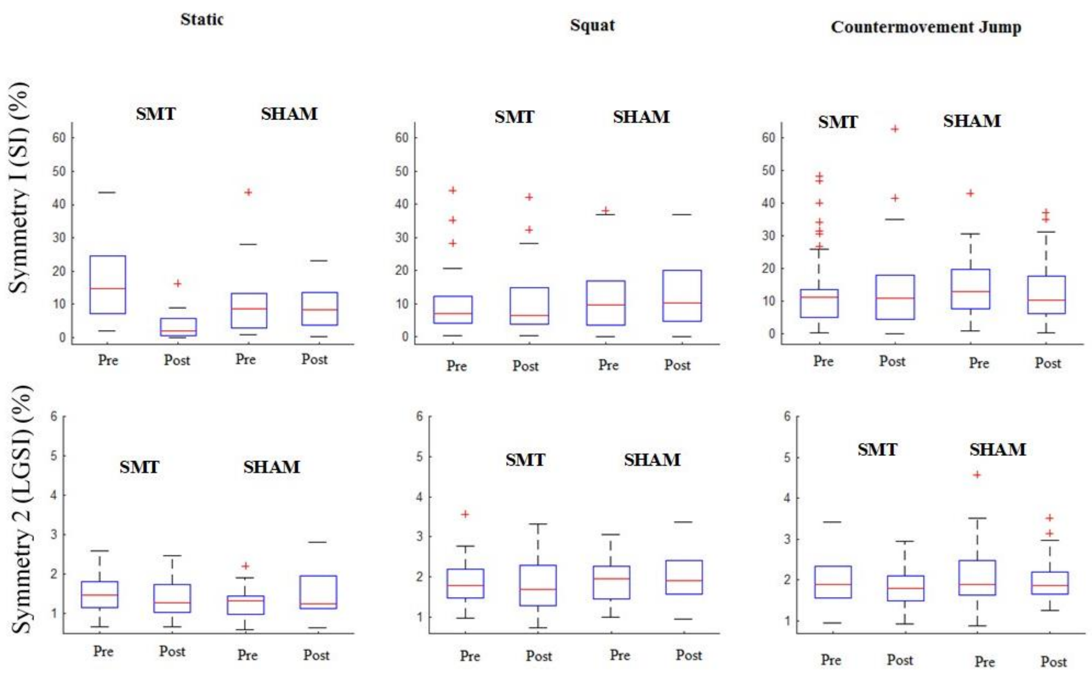

Figure 5 - Visual representation of total symmetry values from both groups. Box-plot: the

small black line: interquartile, superior and inferior limit; the blue box represents: minimal and maximal values; the red line represents: groups means; and the red cross signal: outliers, indicating variability. Both indexes (symmetry 1 and symmetry 2) showing variability values of the physical performance tests (Static, Squat and CMJ).

Statistical significance differences between pre-to-post and between groups, were found, and, described on the table 1 a). Additionally, on the table 1 b) showed the range of symmetry values, pre-to-post SMT and SHAM interventions.

a)

	SMT (N=20)				**SHAM** (N=20)				**p Value**					**(< 0.05)**
	Sym 1		**Sym 2**		**Sym 1**		**Sym 2**		**Symmetry 1**			**Symmetry 2**		
Test	**pre**	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**	***Pg***	***Pm***	***Pi***	***Pg***	***Pm***	***Pi***
STT (%)	16.30 (11.43)	3.77 (4.13)	1.48 (0.48)	1.40 (0.47)	10.75 (10.50)	9.02 (6.18)	1.30 (0.40)	1.46 (0.52)	0.00	0.94	**0.01**[a,b]	0.56	0.71	0.25
SQT (%)	9.37 (8.18)	10.27 (8.90)	1.86 (0.51)	1.82 (0.61)	11.73 (9.55)	12.45 (9.57)	1.90 (0.52)	2.03 (0.57)	0.05	0.49	0.94	0.09	0.55	0.23
CMJ (%)	12.79 (10.71)	13.27 (11.94)	1.96 (0.55)	1.83 (0.49)	13.99 (8.76)	12.40 (8.59)	2.04 (0.66)	1.99 (0.49)	0.90	0.67	0.43	0.09	0.21	0.54

b)

		STT(%)				**SQT(%)**				**CMJ(%)**			
		Sym 1		**Sym 2**		**Sym 1**		**Sym 2**		**Sym 1**		**Sym 2**	
		pre	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**	**pre**	**post**
SMT (N=20)	**min**	1.91	0.10	0.67	0.66	0.31	0.50	0.98	0.74	0.33	0.00	0.95	0.92
	max	43.75	16.11	2.60	2.48	44.07	42.01	3.55	3.31	48.42	62.56	3.43	2.94
SHAM (N=20)	**min**	0.77	0.26	0.61	0.65	0.05	0.00	1.01	0.96	0.90	0.36	0.87	1.26
	max	43.74	23.20	2.21	2.81	38.09	37.06	3.05	3.36	43.12	37.03	4.58	3.51

Table 1 – a) The mean (M), standard deviation (SD) values of two symmetry indexes (%), Sym 1 and Sym 2, were calculated for static trial (STT), squat (SQT) and countermovement jump (CMJ), pre and post lumbar SMT and SHAM interventions for all participants. [a]Significance difference between SMTpre x SMTpost; and [b]SMTpre x SHAMpost. *Pg= P value group: Pm= P value moment; Pi= P value interaction.*

b) The range (minimal and maximal) mean (M) values of two symmetry index (%) were calculated for STT, SQT and CMJ pre and post, interventions, SMT and SHAM.

Discussion

Summary of main findings

In our study, our participants presented bilateral asymmetry values initially in static position, and, post-SMT intervention this values reduced significantly.

The lumbar (SMT) intervention produced immediate effects in static symmetry; however, the same effects were not found in the dynamic tests (squat and CMJ). Statistically significant differences were found between pre-and post-SMT intervention measurements, and, between groups (SMT and SHAM), only for static symmetry. The symmetry 2 showed no statistical significant differences for any of tests, and, in any of groups.

The SHAM group, showed no statistical significant differences between pre-and post-intervention measurements.

Strengths and limitations

Little evidence was found in the literature related to possible effects of SMT on symmetry in athletes. Surpassing this limitations, this study was pioneer to quantitatively measure physical performance test symmetry before and after lumbar SMT intervention to verify if this intervention can effectively produce statistical significant effects.

The main limitation of this study was related to the blinding of therapist to the intervention procedures performed in the participants. The double-blind procedure was not performed because was incompatible with protocol due the inherent difficult to blind the therapist in this type of study. However, instrumental SMT, such as Activator, seems practical to perform these procedures and further investigations involving SHAM versus true interventions could consider incorporating the *Activator instrument.*

Additionally, another limitation was related to posture control variables that were not analysed because incompatibility of our protocol.

Comparison and discussion of findings with respect to previous research

Due to the little evidence found in the literature related to SMT on symmetry, our study was unable to compare results and discuss findings with other studies. Despite of this, all our results were discussed, as follow.

Based on baseline group characteristics, both interventional groups of athletes were similar relative to asymmetry values, according literature(42–46).

Before interventions, the participants presented asymmetry values in the SMT group with mean (M) values of 16,3%, and in the SHAM group presented mean (M) values of 10,7%, indicating that some participants had considerable asymmetry.

Several authors who calculated symmetry based on performance tests(45,47,48), determined the percentage of bilateral asymmetry with values of approximately 10% to 15%. Differences greater than 15% are considered clinically significant(42–46).

Despite some agreement in the literature regarding the asymmetry values of athletes in performance test-based assessments, Noyes et al(41) stated that a symmetry index of 85% or higher is acceptable as a normal range for both genders, and sports activity levels.

Nevertheless, our participants presented initially considerable bilateral asymmetry values in symmetry 1(table 1 a), and, post-SMT intervention, this values reduced significantly to what several authors consider to be the minimum level of bilateral asymmetry, such as reported by Herzog et al,(9) asymmetry values ranging from 4% to 13%.

Clinical relevance and future directions

Adding new information regarding the symmetry influenced by SMT intervention, this study expects to demonstrate that lumbar SMT can effectively produce immediate effects on symmetry in static position, but not in dynamic actions, such as, squat and CMJ. These findings seem to be useful for clinical context in rehabilitative programs of asymptomatic athletes.

Unfortunately, in order to be more relevant in terms of physical and sportive performance, our study would require addressing other variables not found in this present study.

Future studies could be conducted, incorporating more variables, with short-term follow-up, and, two or more groups crossed.

Conclusions

In our randomized controlled study, statistically significant differences were found between pre-and post-SMT, and between groups, only for static symmetry.

Lumbar SMT showed to produce effects in bilateral symmetry in static position when applied therapeutically. Therefore, our findings suggest that a single-session strategy of correcting lumbar vertebral dysfunction through SMT intervention was effective to produce immediate effects on symmetry in static standing position. However, in dynamic tests (squat and CMJ), pre-to-post lumbar SMT and SHAM were no statistically significant differences in terms of symmetry.

Future studies could to address our study limitations.

- "What are the new findings"

- Asymptomatic athletes' participants presented static bilateral asymmetry prior the interventions, from pre- 16,3%, and after interventions, reduced significantly to 3,7%, immediately post lumbar SMT intervention;
- The Lumbar (SMT) intervention produced immediate effects on static symmetry; but the same effects were not found in dynamic tests (squat and CMJ);
- No statistical significant effects were found in symmetry, pre-to-post SHAM in any of the physical performance tests.

- "How might it impact on clinical practice in the near future"

- In our randomized controlled study, lumbar SMT produced immediate effects on symmetry in static standing position when applied therapeutically, but not in dynamic actions. Thus, this study expects to demonstrate that the single-session strategy of correcting the lumbar vertebral dysfunctions through lumbar SMT can effectively produce immediate effects in static symmetry;
- Adding new information regarding to the static symmetry influenced by lumbar SMT intervention, these findings seem to be useful for clinical context in rehabilitation programs of athletes.

Competing interests: None declared between authors.

Contributorship: The randomized controlled study was completed, and all authors authorized the final version of the manuscript.

The concept development; design; international clinical trial registration; local ethics council submissions; participant recruitment and allocation; clinical examinations; selection; experimental and control interventions, SMT and SHAM; data capture, collection and processing; biomechanics parameter and statistical calculations; analysis/interpretation; and writing of the report were performed by B.A.P.A. The concept development, design, supervision, statistical analysis/interpretation and writing were performed by B.A.P.A, R.F.W, F.O.S.J, J.P.L and A.P.V. All other contributions to this work (critical review and writing a substantive part of the manuscript) were equally distributed among the authors.

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Ethics approval: FMH - Ethic Committee Register number: 31/2017.

Data sharing statement:

All participants submitted a signed informed consent form (FMH - institutional consent) that included information about the purpose of the study, its procedures, the participants' rights and welfare, participants' protections and the collection of data for publication.

The patient information sheet is not currently available in web format; please use the contact details below to request patient information. Individual data (the biomechanical outcomes of the individual study participants showing outcomes related to performance tests symmetry and the therapeutic intervention) will be shared starting on 15/12/2018 upon previous communication and solicitation by responsible study contact personnel, as indicated.

The dataset used and/or analysed during the currently study is available from the corresponding author, B.A.P.A, on reasonable request. Data sharing is available by request from the corresponding author. All data generated or analysed in this study was included in the submitted article in the main manuscript document and supplementary material.

The datasets analysed are available from the Biomechanics and Functional Morphology Laboratory, Faculty of Human Kinetics, FMH, University of Lisbon, upon request and authorization (Estrada da Costa, Dafundo. Lisboa, 1499-002, Portugal). Websites: www.fmh.ulisboa.pt; www.neuromechanics.fmh.ulisboa.pt.

The outcomes of this study are expected to be presented as an original article in scientific publications, such as a high-impact peer-reviewed journal and/or congress, seminars and conferences presentations.

Our biomechanics laboratory team supported the procedures and decisions to take new approaches and encouraged the submission of this report for registration in international platforms, according manuscript publication recommendations. In this sense, we expect to follow all requirements for submission to relevant scientific journals and to share consistent and relevant results with the public.

Clinical Trials Register number: NCT03361592.

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General Discussion

5

Discussion

The aim of this thesis was quantitatively measure the immediate effects of lumbar SMT on symmetry parameters of asymptomatic athletes, thru functional performance tests: static posture, squat movement, and vertical jump countermovement, over force platform and marker based optical 3D motion capture,

In daily practice, many clinicians often detect physical impairments and movements pattern deviations of athletes, such as bilateral asymmetries, but not always, applying therapeutic intervention to correct it. However, we believe that any decrease of percentage in bilateral asymmetry, immediately after lumbar SMT could be related with the changes on neuro-musculoskeletal system described on literature (Descarreaux et al., 2006; Grindstaff et al., 2009; Miners & Fccss, 2010a, 2010b; Pollard H, 1996).

The literature has consistently pointed out that SMT changes the neuro-musculoskeletal system, altering the sensory and neurological signs, and having impact on proprioceptive primary afferent neurons from paraspinal tissues, improving physiological function and altering local and periphery motor control system, increasing co-ordination and neurological actions, flowing through the spinal structures that are involved in mechanism of transmission and movement coordination between the upper and lower limbs. Also have been demonstrated, relative to lower limbs, SMT changes muscle activation and force output in individuals with and without low back pain, were demonstrated for several authors namely in the gluteus, hamstrings, quadriceps, soleus, and gastrocnemius.

In this sense, we can speculate that neuro-musculoskeletal adaptations of bilateral asymmetry pattern on functional tests, in asymptomatic athletes are of clinical importance and that clinicians should assess them.

Relative to ability to consistently measure and distinguish different levels of functional symmetry were implemented in our protocol two symmetry indices, each index with one purpose, the symmetry index (SI) for assess local kinetic symmetry and LGSI for assess linear global kinematic symmetry.

This thesis comprises to measure symmetry by functional performance tests, before and after SMT and SHAM interventions, to quantify the immediate effects between groups based on statistical calculations.

Considerable evidence, available froth the studies presented in (chapters 2 to 4) of this thesis, supports the idea that SMT could produce immediate effects on bilateral symmetry. Measurements results obtained using force platform and 3D motion capture system are reproducible in test-retest situations.

Therefore, our investigation seeks to improve better understanding the mechanisms behind of the SMT changes in symmetry after therapeutic intervention. Hence, to identify the appropriate outcomes as “main symmetry patterns” and to reliable compare SMT group and SHAM take into account the intervention applied and the variances, two reliability evaluations were conducted.

In this chapter the main results of this thesis are overviewed and discussed. The detailed discussion was presented and the main findings of each of three studies, were presented. Thus, to address important methodological considerations leading to the refinement of this theme, we provided the general conclusion and suggestions for future research.

Main findings

Study 1 – Preliminary feasibility study

The main findings regarding kinetic parameters showed statistical significance between pre to post lumbar SMT intervention in lower limbs reaction forces symmetry on static posture, 14,4% pre and 3.8% post being calculated using $P<0.05$ and effect size 0,35. The range (minimum and maximum values) mean of symmetry values for all participants were initially 1,9 – 31,1%, on phase pre, indicating that some athletes’ participants were prior asymmetric based on literature values. Several authors calculated symmetry in functional tests (Fousekis, Tsepis, & Vagenas, 2010; Linthorne, 2001; McGrath et al., 2015), namely vertical jumps and concluded that lateral differences greater than 15% are considered clinically significant (Almeida et al., 2016; Antunes et al., 2013; Menzel, et al, 2013; Noyes, Barber, & Mangine, 1991), but none of them applied therapeutic interventional protocol, under performance tests to verify the behavior of the bilateral symmetry after intervention.

Therefore, our findings suggest a therapeutic strategy of correcting the lumbar vertebral dysfunctions through SMT intervention, influence the biomechanics parameters, affecting the neuro- musculoskeletal system, namely on postural muscles, the anti-gravitational ones. In static posture symmetry test (Cramer, Budgell, Henderson, Khalsa, & Pickar, 1997; Grindstaff, Hertel, Beazell, Magrum, & Ingersoll, 2009; Pollard H, 1996).

The results of this preliminary study showed that statistical significant differences were found in lumbar SMT, only for static posture symmetry for this group of asymptomatic athletes’ participants. However, a great increase in bilateral symmetry on static symmetry percentage was seen, but none in dynamic tests; which deserves further investigations.

Nevertheless, this ´pilot study´ demonstrates that a larger study to evaluate if lumbar SMT affects bilateral symmetry is feasible.

Study 2 – Intra-rater, test-retest reliability study

Our statistical findings indicated high levels of intra-rater, intra-session reliability, reflecting on consistency of our results about kinetic and kinematic symmetry index, obtained by performance tests before and after SMT intervention, in single session, test and retest assessments.

Thru reliable statistical pack calculations, reliability and reproducibility were analyzing by the closeness of the agreement between the results of same measurement carried out by different instants (Pre-Post phases), while repeatability was defined by proximity between the results of successive measurements carry out the same rater/observer. Finally, accuracy was determined by the proximity between the actual values and measurements results.

For the reliability study, the hypothesis around intra-rater and intra-session test-retest reliability of functional performance tests, was find acceptable intra-rater reliability scores more than half values, or at least presenting scores better than poor reliability. For reproducibility, repeatability and accuracy of the measurements were tested, supported by the proposed concept from guidelines for this type of evaluations and applications (Possolo, 2016; Taylor & Kuyatt, 1994).

In line with the literature, but taking account that no studies provided protocol like us, our findings on Symmetry (1), presented an excellent relative reliability for Static Posture (ICC=0.92). Good relative reliability of ground reaction forces was also noted during the Squat (ICC=0.77). Countermovement Jump presented (ICC=0.71) showing larger relative reliability.

For absolute reliability were calculated the standard errors of symmetry measurements and the results indicated low levels of intra-session errors during test-retest physical performance assessments, varying of 3 tests since (3.0), (3.1) to (4.3).

Relative to minimal detectible changes at 95% confidence interval, our results presented lower and similar values between physical performance tests with difference of (0.2 to 0.4), namely in Static, Squat and countermovement jump, varying to (8.5), (8.7) to (9.1) respectively.

Static trials presents lowest values of minimal detectible changes (8.5) and the countermovement jump the highest minimal change (9.1).

Symmetry 2 measured outcomes presented also good relative reliability of ground reaction forces noted during Static trials (ICC=0.78.) The Squat presented moderated relative reliability (ICC=0.61), and the countermovement jump has an excellent relative reliability

(ICC=0.93).

For absolute reliability, kinematic symmetry 2 also exhibited lowers standard errors of measurements from all physical performance assessments intra-session, varying since 0.1 to 0.3. Between assessments, countermovement jump, showed lowest values of measurements errors (0.1).

The minimal detectible changes with 95% confidence interval presented, were also considered lower in kinematic symmetry 2, with range varying of lowest (1.7) for the Countermovement Jump and highest (4.2) for Squat, indicating that for kinematic symmetry of physical performance tests, the minimal detectible changes were wide lower.

For kinetic and kinematic symmetry indexes, both exhibited lower, acceptable measurement errors varying from (0,1 to 4.3) and minimum change detected varying from (1.7 to 9.1).

Therefore, our “reliable pack” displayed of good relative and absolute reliability confirming the accuracy of the intra-rater, intra-session, test-retest reliability and reproducibility of performance tests measurements, drawing thus consistent results. Researchers should consider this methodological protocol to measure test-retest physical performance tests symmetry, between SMT intervention, taking account the relative and absolute reliability, error of measurements and minimal detectible changes of the study variables.

Despite of results, our focus was reliability only not on validation of our protocol. To construct validation is necessary large sample size, because they are direct related and in our study the sample size was not large. However, discriminative validity has to be proven by further research.

Study 3 – Randomized controlled trial study

The main findings of our randomized controlled study, indicated statistically significant differences found between pre-and post-SMT, and between groups, only for static symmetry.

Lumbar SMT showed to produce effects in bilateral symmetry in static position when applied therapeutically. Therefore, our findings suggest that a single-session strategy of correcting lumbar vertebral dysfunction through SMT intervention was effective to produce immediate effects on symmetry in static standing position. However, in dynamic tests (squat and CMJ), pre-to-post lumbar SMT and SHAM were no statistically significant differences in terms of symmetry.

For the Group 1, symmetry 1, the measured outcomes seem to be better post than pre phase, between lumbar SMT intervention on functional performance test. There was statistic significant between pre to post lumbar SMT intervention in ground reaction forces (GRF) symmetry on Static Posture (orthostatic position) with mean and standard deviation values on pre phase, of 16,3%, 11; and post phase 3,8%, 4,1 respectively.

The results indicated an immediate larger increase in lower limbs reaction forces symmetry on static posture trials, presenting pre and post Kinetic symmetry differences of 12,5%.

Noyes et al, 1991, states that a bilateral symmetry of 85% or greater are acceptable as a normal range for both males and females regardless of dominance, sports activity level,' or gender. According this author "deviations from perfect bilateral symmetry, in a normally symmetric body, could be a signal of lack of developmental precision (Noyes et al., 1991). In other hand Herzog et al. 1989, described ground reaction forces asymmetry values for gait and considered normal upper and lower limbs symmetry difference values ranged from 4% to 13%. According Menzel et al, 2013; McGrath et al 2015 and Impellizzeri et al 2007, who measured functional test symmetry between elite athletes through different vertical jumps over force platforms, considered bilateral asymmetry values between 10-15% relevant for the classification of individuals as symmetric or asymmetrical and values greater than 15% are considered clinically significant. In this sense, our findings are partially in line with several authors that calculated functional tests symmetry but none of them applied therapeutic intervention between functional performance tests. Our results showed range (minimum and maximum values) of kinetic symmetry mean varying initially from 1,9 to 43,75% respectively, indicating that several asymptomatic athletes' participants were prior asymmetric based on literature values, showing extreme kinetic symmetry differences values. This extreme values of bilateral symmetry obtained after statistical analyzes could indicate functional bilateral asymmetries or structural intra-limbs differences such as leg length inequality.

This maybe representative of the immediate effects of lower limbs reaction forces symmetry in static posture for clinical and sportive contexts, which more symmetrical could enhance functional performance tests on posture maintenance, becoming more balanced relative at weight distribution over force platform, thus reducing the possibility of biomechanics joint stress and injuries. In this stand lumbar SMT may be beneficial for improve immediately lower limbs reaction forces symmetry on static posture of asymptomatic athletes. Therefore, in participants who received lumbar SMT intervention to correct biomechanics dysfunctions on lumbar spine was observed changes on symmetry outside de standard errors of measurements relative to kinetic symmetry. In terms of clinical and sportive relevance, we can verify greater improvement of symmetry, on asymptomatic athletes 'participants.

Therefore, we believed that these decrease in percentage of asymmetry on functional tests immediately after lumbar SMT in athletes could be related with the changes on neuro-musculoskeletal system described on literature, especially because the postural control is an important evaluating physical performance and its depends of many other factors, neurologic, orthopedic and functional, as well age and gender. Because the two feet supporting the human body, delineating small zones of support, and because a significant mass is carried in the upper part of the body, maintaining balance in standing posture and during events poses, is a serious challenge to the central nervous system.

Standing and weight superimposed by such structures is distributed from the fifth lumbar vertebra to the sacrum and through the pelvis to the symphysis pubis and the heads of the femurs, and then down to the ground and ground reaction force would be the same, but in the opposite direction. Reducing ground reaction forces misbalances and biomechanical stress of the joints, are extremely important for musculoskeletal functional changes, became more symmetrical in relation of functional performance after one single SMT intervention.

Postural regulation is organized in hierarchical and stereotypic patterns and requires the central integration of afferent inputs from the sensory systems as well as the motor command of antigravity muscles. The activation of postural muscles is organized in synergies (activation/inhibition of agonists/antagonists muscles) and is based on postural neural networks.

Each sensory, central, and motor component of the postural function is either healthy or pathological ("health" – asymptomatic and "pathological" – symptomatic) will display normal or abnormal functions. In pathological subjects, the dysfunction of certain parts involved in postural control is likely to amplify body sway and/or to affect the ability to cushion it and it may also alter the segmental organization of postural control affecting functional performance.

In this sense, our results indicated that single lumbar (SMT) may significantly improve lower limbs reaction forces symmetry becoming more balanced relative at bilateral weight distribution in static posture of asymptomatic athletes' participants. Thus these results can suggest that SMT generates different neuro modulatory, peripheral and cortical changes when applied therapeutically and this study contributed to a greater detail when looking to symmetry patterns on static posture in asymptomatic athletes.

Nevertheless, these changes, can interfere with physical performance of many of functional tasks, but the same not happened with dynamic actions, SMT not alter significantly dynamic movements, namely squat and CMJ. For both groups, the manifestations of this dynamic variables seem not have any significant effect on symmetry and the results not appear be clinically and sportive meaningful.

According therapeutic interventions literature, still little evidence that (SMT) can be beneficial effectively in dynamic movements. In this way, our protocol through dynamic tests, squat exercise and (CMJ) high, showed not statistical and clinical significance in terms of dynamic actions.

This would assist in addressing effectiveness of the possible short-term efficacy of the treatment protocols utilized in all treatments administered within a set timeframe to allow a direct and accurate comparison of the effect of each treatment and the overall efficacy.

Further studies should evaluate reliability over longer lengths of time and include several sessions, raters and groups to control for learning much more about the effects especially about the mechanism whereby the symmetry deficit between limbs is enhanced following spinal manipulation, and the durability of this effect. The clinical significance of the reduction in symmetry differences between limbs needs testing in future studies to determine if it actually prevents occurrence of future injury, keeping the bilateral symmetry intra-limbs. This model is believed to proper address duration of SMT effects, accumulation of such effects and to discover an ideal number of interventions and momentum for treatment during training or prior to a competition event.

Future research should also retrieve the bio-psychometric factors between athletes' participants' and evaluate the subjective perception of effort, during collecting data, such as PROMS recommended and important for analysis and could perform before and after performance test, after intervention.

Nevertheless, new clinical and sportive investigations could complement this randomized controlled study, surpassing all limitations mentioned above.

Conclusion

The work in this thesis consists of preliminary steps in the development of the methodological interventional protocol and the application of therapeutic interventions between functional performance actions, to measure and evaluate the outcome measures obtained by two symmetry indexes, that can be used as real time feedback, in sportive rehabilitation programs to improve bilateral symmetry in functional performance of asymptomatic athletes.

The present series of studies showed that the initially proposed pilot study was able to show preliminarily the influence of SMT on lower limbs reaction forces symmetry by symmetry index (SI), thus being sensitive to changes that occurred within the same session, but unfortunately in our investigation, we not provided different sessions to compare and check consistence of measurements inter-session.

Relative to kinematic symmetry index applied, our data during functional performance tests, not showed statistical and clinical significance in terms of immediate effects on static and dynamic movements. Despite of this findings, the LGSI index presented satisfactory levels of relative and absolute reliability, and lowers standard errors, been recognized as able to detect high kinematic asymmetry in functional performance tests, in repetitive measure, such as gait.

The most of the founds on our investigation with relation of SMT with immediate effects of kinetic and kinematic parameters, showed that SMT led to improved lower limbs reaction forces symmetry in static performance test. These results can suggest that lumbar SMT generates different neuro modulatory, peripheral and cortical changes when applied therapeutically, and this study contributed to a greater detail when looking to symmetry patterns on functional performance tests, in asymptomatic athletes. However, our results are in agreement with literature about the possible changes on neuro-musculoskeletal system after lumbar SMT intervention. These changes can interfere with the physical performance of many functional tasks, but there is still little evidence that (SMT) can be effectively beneficial in dynamic movements, as Squat exercise and Countermovement Jump.

Therefore, despite the common contention of some athletes and sports-related professionals that SMT enhances physical and sports performance, our findings revealed that such a claim is not supported by current evidence. Spinal manipulative therapy may be a promising approach for performance enhancement of symmetry in static posture actions, but it needs to be better and more deeply investigated for dynamic actions commonly performed in sports practices.

Methodological considerations

Although the materials and methods used to carry out the studies included in this thesis are described with details in chapters 2 to 4, there are still some noteworthy methodological considerations that will be addressed in the following paragraphs.

Methodological study protocol

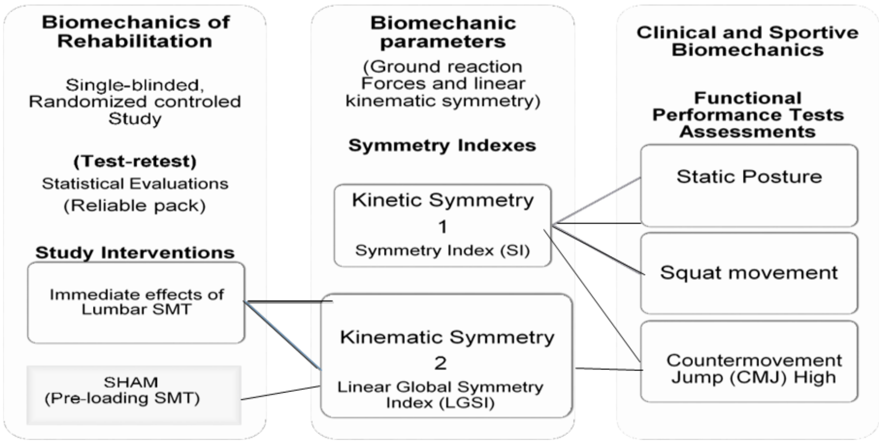

Figure 1 - Practical and Theoretical approach to support and give consistent results in this study.

Intra-rater, intra-session, single-blinded, test-retest of functional performance tasks, standard errors of measures, minimal detectible changes and minimal clinically important were applied for kinetic and kinematic symmetry outcome measures after SMT intervention.

Materials and methods

Kinetic parameters were collected thru functional performance tests (Cappozzo, Catani, Leardini, Benedetti, & Della Croce, 1996; Seay, Selbie, & Hamill, 2008). A motion capture systems *Qualisys QTM software, (Gothenburg, Sweden)* with 15 cameras “Oqus 300”, frequency of 179 Hz, were used for static and dynamic data captures. QTM was used for tracking the reflective body markers that were placed about 8 segments, thoracic, lumbar, pelvis, and lower limbs including, knee, ankle (medial and lateral), heads of the 3 metatarsals and heels. Four "clusters" of rigidly placed reflective markers to the thigh and shank where also fixed bilaterally in the thigh and shank (Cappozzo, A., Catani, F., Della Croce, U. & Leardini (2010).

Two *Kistler* force platforms *(Winterthur, Switzerland)* with piezoelectric sensors were used to capture highly static and dynamic activities operating at 500 Hz were used to collect ground reaction forces (GRF) The data was analyzed in Visual 3D software *(Germantown, MD, US*A) were created the biomechanics model for application in static and dynamic tests for our investigation.

Prior to acquisition of kinetic and kinematic parameters, demographic anthropometric data constituted of age, body weight and height measurements for each participant were recorded. Before functional performance tests was given 5 minutes for each participant to be familiar with the tasks and procedures of data collections.

To collect this type of data using two symmetry indexes, with optoelectronic systems were necessary calibration (Hoerzer, Federolf, Maurer, Baltich, & Nigg, 2015; Lund, Andersen, de Zee, & Rasmussen, 2015; Nigg, Vienneau, Maurer, & Nigg, 2013). The marker set and model used in this study were based on the calibrated anatomical system technique (CAST) (Hoerzer et al., 2015; Lund et al., 2015; Nigg et al., 2013).

Participants were invited to show their performance through functional performance tests, before (pre-test) and after (post-test) lumbar SMT intervention. A total of 14 trials of 3 functional performance tests (Static posture, Squat movement and CMJ) for each participant and for all researcher participants between studies such as: Study 1 (n:13) – 182 trials, Study 2 (n:20) – 280 trials and Study 3 (n:40) - 560 trials.

The athlete´s placed over force platform, with one side in each force platform, starts pre-test with three consecutive tasks, Static Position recorded in 10 seconds, Free Squat in 3 repetitions and Countermovement Jump, also recorded in 3 repetitions. After the pre-test, the participants received the therapeutic intervention lumbar SMT and after that they performed the post-test, with the same tasks and sequence of pre-test of study protocol. Data were recorded in pre and post phases, thus obtaining outcome measures of ground reaction forces (GRF) and joint vectors center displacement. After obtained this data, values were normalized by mass, to them apply the equations (eq.1) and equation (eq.2) for symmetry index (SI) and linear global symmetry index (LGSI) calculations and statistical analysis, for all participants. Normalized data were performed prior other statistical calculations relative to two symmetry indexes applied, kinetic at local level and Kinematic at global level.

Marker set and modelling

The markers were selected and positioned by convenience, according markers set-up protocol, by previous preliminary study performed by laboratory team.

Markers placement points were drawn on participants' body, with a water-soluble pen to ensure fast and reliable location during the experimental procedure of placement and replacements of markers.

Body markers were placed in the thoracic, lumbar, pelvis, and lower limbs including, knee, ankle (medial and lateral), heads of the 3 metatarsals and heels, for while standing calibration test. A total of 49 reflective markers, 5 "clusters" of rigidly placed with 3-4 reflective markers to the lumbar area, thigh and shank, where also fixed bilaterally (Cappozzo, A., Catani, F., Della Croce, U. & Leardini, 1995., Seay J, Selbie WS, Hamill J. 2008) as showed on Figure 1 below for Kinetic and Kinematic parameters of data collection (Static and Dynamic tasks) in functional performance tests applied (Cappozzo et al., 1996; Seay et al., 2008).

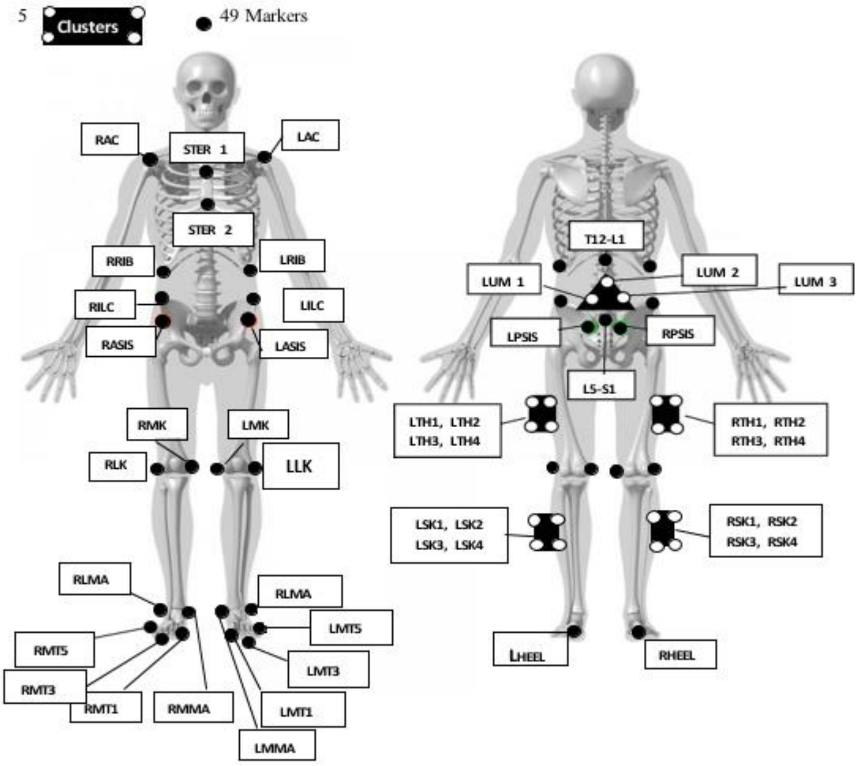

Figure 2 - Anterior (left) and posterior (right) views of 49 marker placement and 5 rigid clusters with 4 markers each, were placed on the lateral aspect of thighs and shanks.

Three-dimensional model choice

Three-dimensional motion analysis requires the determination of the instantaneous pose (position and orientation) of segments (Cappozzo et al., 1996). The quality of the results depends on the chosen marker set and the pose estimation algorithm, and on the conventions to represent model based items (i.e. linear joint center vectors displacement). Although the use of conventional physical performance tests models is more appealing to clinical practice due to the reduced number of markers and cameras needed (Zeni, Richards, & Higginson, 2008) these models are more likely to error. Namely, given their use of direct pose estimation methods (non-optimal), the segments' coordinate systems are computed at each frame of the motion trial as they are in the static calibration trial, thus making no assumption about the rigidity of the bodies. Consequently, these models have a minimal ability to compensate for soft tissue artifact, as an error in the placement of a marker results in a direct error in the estimation of the segment's coordinate system (Ali, Robertson, & Rouhi, 2014; Lund et al., 2015) Furthermore, the coordinate system of the distal segment is computed using a virtual joint center that is created with reference to the proximal segment, which means that errors in the pose of the proximal segments propagate to the distal segments. Finally, using this shared virtual joint center and constraining the translational degrees of freedom may introduce unnecessary errors in the angular kinematics (Bund, Ghorbani, & Rathjens, 2016; Guo & Xiong, 2017) While six degrees of freedom models are still affected by soft tissue artifact and marker placement imprecision, they overcome the theoretical limitations of conventional functional tests such as gait models and are highly reliable (Collins & Scholar, 2003).

Taking this into account, the marker set and model used in this thesis were based on the calibrated anatomical system technique (CAST) (Cappozzo, Catan, Crocel, & Leardini, 1995). Explicitly, the model was composed of 8 independent rigid segments (trunk, pelvis, thighs, shanks and feet). The pelvis was created based on the CODA pelvis model (Ali et al., 2014). The remaining segments were created so that their frontal planes were defined by the medial and lateral markers at the distal extremity and by the midpoint between the markers at the proximal extremity (or by the proximal virtual joint center, in the case of the thigh). Additionally, the longitudinal axis is created from the midpoint between the aforementioned markers of the distal extremity to the midpoint (or virtual joint) at the proximal extremity the origin. Subsequently, the anterior-posterior axis is created using the cross-product between the longitudinal axis and the frontal plane, and finally the medial-lateral axis is created from the cross-product between the longitudinal and the anterior-posterior axes. These coordinate systems are therefore orthogonal, right handed and distally biased, with the medial-lateral axis pointing to the right.

Symmetry calculations

Our long term goal is to improve the clinician's ability to detect, measure, restore and prevent bilateral asymmetries through interventional protocols. A prerequisite for restoring symmetry is the use of symmetry scores that are precisely defined and relevant to the context of the assessment and the therapy. Previous studies using biofeedback for gait symmetry use discrete local metrics, such as stance time asymmetry (Nigg et al., 2013) or peak vertical ground reaction force asymmetry.

A typical symmetry index utilized in our investigation, measure the kinetic symmetry by percent difference of a metric between two sides such as the Symmetry Index (SI) utilized on our investigation (Robinson, Herzog, & Nigg, 1987): Using the SI, McCrory and colleagues (Gurney, 2002; McCaw & Bates, 1991) found that a group of pain free individuals with a history of hip replacement were more asymmetrical with regards to a selection of discrete loading parameters than a group of healthy controls. Furthermore, the SI was also shown to be able to distinguish pathological pattern such as stroke patients from healthy individuals (Patterson, K. K., Gage, W. H., Brooks, D., Black, S. E.,

& McIlroy, 2009) but in gait analyzes. Several researchers of sportive and clinical context, measure static and dynamic symmetry by functional test and also utilized this symmetry index (Clark, 2001; Hans-Joachim Menzel, 2013 , Silvia Ribeiro Araújo, 2006).

Bilateral asymmetry scores (SI%) in static position, pre and post Lumbar SMT in group of asymptomatic athletes' participants.

Bilateral asymmetry % scores	**Symmetry Index (SI%)**	**Symmetry Index (SI%)**
Study 1 (n:13)	Pre: 14,4%	Post: 3,7%
Study 2 (n:20)	Pre: 16,3%	Post: 3,8%
Study 3 (n:20)	Pre: 16,3%	Post: 3,8%

Table 1 - Summary of study results relative to bilateral asymmetry mean scores in percentage %.

The first index, symmetry index (SI%) was based on a review of the candidate indices in the literature and was applied to evaluate the test-retest kinetic symmetry scores obtained in lower limbs reaction forces, by two force platforms. The index was applied on preliminary tests of its repeatability to consistently measure lower limbs symmetry in the same individual and to reliably distinguish between individuals. The second index was applied to measure kinematic symmetry on test-retest functional performance tests, in a group of asymptomatic athletes.

One important limitation was about the two symmetry indexes utilized. Both indexes presented good reliability and agreement intra-rater and intra-session on test-retest functional tests.

According literature related, the symmetry index SI utilized was potential to artificially inflate asymmetry levels. Thus, symmetry ratio as symmetry Index (SI) can also artificially inflate the level of asymmetry when the values are small. This inflation can occur when the reference value is small in comparison to the bilateral difference, which may not even be clinically relevant, and were not observed in our study. Conversely, differences that are small in comparison to the reference value tend to lower the final score, thus falsely reflecting symmetry.

Relative to symmetry index 2, linear global joint center vectors displacement maybe was not representative to observe the direction of the asymmetry during dynamic and explosive actions, and more development of this symmetry index could take place for identify the symmetry direction during all cycle of functional performance tests.

Therefore, we could interpret this as lost reliability in specific points of the functional performance test symmetry cycle. A possible reason for poor reliability could be the error associated with marker placement. Although, it has been proposed as a rule of thumb for clinicians and sportive researchers.

A limitation of the SI is the potential for artificial inflation (Herzog W, Nigg BM, Read LJ, 1989). This inflation can occur when clinically irrelevant differences between sides are divided by a much smaller reference value (Zifchock, Davis, Higginson, & Royer, 2008b).

Similarly, parameters that have large values but relatively small inter-limb differences tend to lower the index and reflect symmetry (Sadeghi, Allard, Prince, & Labelle, 2000).

Another limitation of the SI% is the choice of a reference value (i.e. the denominator in equation 1), which is chosen differently based on the question being asked (Sadeghi et al., 2000). In the presence of large asymmetries, using the average value of both limbs may not correctly reflect the performance of either limb ((Sadeghi et al., 2000) and tends to mask the asymmetry by lowering the SI value (Sadeghi et al., 2000), but choosing one side as the reference may not always be easy or the most appropriate. Lastly, the use of different reference values for the same data yields different results, and makes the comparison of results from different studies and samples difficult (Zifchock, Davis, Higginson, & Royer, 2008a). Simple symmetry measures such as the SI are useful at a local level, but it is difficult to make conclusive statements about the global aspect of gait symmetry and the influence of specific interventions when analyzing a multitude of asymmetry values per subject (Hoerzer et al., 2015). Attempts to restore symmetry in a particular biomechanical parameter might lead to adaptations in other parameters, which should not be neglected or ignored (Sadeghi et al., 2000).

The isolated optimization of an individual metric may not necessarily mean that the overall functional performance test symmetry is improved because there are a variety of control strategies that can be used to change discrete and local metrics like these and trying to consciously control these many degrees of freedom is nearly impossible ((Hossener & Wenderoth, 2007). On the other hand, learning from a single, but more global, feedback measure requires the subject to rely more on sources of intrinsic feedback, and therefore on implicit learning processes.

Global symmetry measures comprising multiple discrete metrics, such as the composite score (Deluzio, K. J., Harrison, A. J., Coffey, N., & Caldwell, G. E. In D. G. E. Robertson, F. E. Caldwell, J. Hamill, 2014), have been developed. A limitation of using discrete metrics is that they neglect the temporal information in gait waveforms and their extraction is subjective and potentially difficult in atypical waveforms (Deluzio, K. J., Harrison, A. J., Coffey, N., & Caldwell, G. E. In D. G. E. Robertson, G. E. Caldwell, J. Hamill, 2014). With this in mind, global symmetry measures, i.e. a single score that provides information about the symmetry of a collection of local parameters, could be a useful tool from a rehabilitation perspective.

Take it account, global symmetry measures, could be a useful tool from a rehabilitation perspective, because one single score, could provide information about the symmetry of collection data of local parameters. This means that important asymmetries could potentially be missed if for example the ground reaction forces on both sides, despite being of similar magnitude, occurred at different times in the functional performance tests cycle (Nigg et al., 2013).

Another challenge is that the asymmetry is only significant if the difference observed between limbs is larger than the difference within limbs. The composite score attempts to overcome this limitation by assuring that asymmetry is only reported if the inter-limb differences are larger than the intra-limb differences (Deluzio, K. J., Harrison, A. J., Coffey, N., & Caldwell, G. E. In D. G. E. Robertson, G. E. Caldwell, J. Hamill, 2014). Unfortunately, because our protocol only variables with inter-limb differences test-retest (pre and post interventions) in the same session, the intra-limb differences observations over the time was not possible to perform, but further studies could address to evaluate the same subject over time.

Some global measures of symmetry include continuous kinematic and/or kinetic parameters. The strength of global symmetry measures composed of continuous variables is their ability to reduce all the information from various local parameters throughout the functional performance tests waveform in one score.

Two symmetry scores (Hoerzer et al., 2015; Nigg et al., 2013) measured the difference between joint parameters on both sides of the body, but during gait functional tests. These researchers have conflicting results that could be explained by the different symmetry measures used in the different studies. Among other differences, the symmetry indices used in the aforementioned studies were mainly composed of joint parameters, while our score is solely composed by joint center vectors displacement.

Recently, Nigg and collaborators (Nigg et al., 2013) suggested that splitting the symmetry score into categories that represent the different planes of motion is preferred over a general measure of symmetry as it provides more information to tailor the clinical intervention to the patient's specific needs. Additionally, it can be reported such as it is and/or broken down into its components to provide the clinician with further information about the source of the asymmetry, and therefore help to guide the clinical assessment and rehabilitation goals.

The LGGA score was developed by Cabral S et al (Cabral, Fernandes, Selbie, Moniz-Pereira, & Veloso, 2017) with goals of being used as real-time biofeedback in gait retraining programs, as a complement to traditional patient care. In our investigation we decided to use this index but adapting for functional performance tests to measure the kinematic symmetry. For this reason, we called this index by Kinematic Symmetry 2, meaning the linear global joint centers vectors displacements, adapted by Cabral S et al (Cabral, Fernandes, Selbie, Moniz-Pereira, & Veloso, 2017).

In conclusion, this study tested the LGSI by analyzing asymmetrical functional performance movements, and showed that this score was not able to distinguish different levels of asymmetry, especially because the scores from this index are close t. We still need to analyze the score's repeatability over different testing sessions and its ability to distinguish groups of individuals with clinically identified differences. Improvements can also be made to address the lower reliability of variables outside of the sagittal plane, or to tailor the score to specific clinical conditions. More cost effective modalities need to be explored for those without 3D optical motion capture systems. The focus on a symmetry score based only on kinematics facilitates the translation to other common modalities (e.g. Inertial Measurement Units, or accelerometers) that are predominantly kinematic.

This decomposition of a global score into its components may be advantageous in that local symmetry indexes, providing useful insights as to which components contribute more to the overall score as (McGinley, Baker, Wolfe, & Morris, 2009). This can easily be achieved with the LGSI score by simply not adding up the 15 kinematic variables that compose the score, or by adding them separately according to the plane of motion. Thus, according developers LGSI scores by (Cabral, Fernandes, Selbie, Moniz-Pereira, & Veloso, 2017), could easily be adapted to the needs of the clinician, providing more information when needed, but more update could be necessary in the future for establishment in different contexts.

Figure 3 - Vectors for the Euclidean distances computed during the right side (performance tests) and during the left side (performance tests) LGSI calculations (Adapted from LGGA by (Cabral, Fernandes, Selbie, Moniz-Pereira, & Veloso, 2017).

The division of the bilateral differences in each variable by its corresponding range of motion means that the variables in these planes are divided by a smaller value (because the range of motion is smaller), which results in higher asymmetry scores. Because that the quality of our symmetry 2 results, present unfamiliar values, thus the agreement of the mean scores were converted and expressed in percentage (%), reported higher asymmetry values in the transverse and frontal plane variables, and highlight that these variables are less reliable than those in the sagittal plane. It is possible that these higher scores could have been inflated by the normalization procedure used.

One of the limitations of the LGSI (symmetry index 2) score is that it neglects the direction of the asymmetries it neglects the direction of the asymmetries for example if is unable to indicate which side presents larger values and also the direction of asymmetry or which point of the cycle was less reliable. While the amount of asymmetry may be the same (for an equal bilateral difference) the information about the direction may be clinically relevant (Gabor J. Barton, Malcolm B. Hawken, 2015). However, with the LGSI score, introducing the direction of asymmetry could mask important asymmetries caused by compensations, as demonstrated by Roerdink et al (Gabor J. Barton, Malcolm B. Hawken, 2015). Additionally, the lack of normalization does not allow for other physical quantities (i.e.

kinetics) to be directly incorporated into the LGSI score. However, it is possible that normalizing the score by dividing the bilateral differences by a reference number may contribute to the artificial inflation or lack of sensitivity that has been pointed as limitations in other scores.

In terms of validity, in the absence of a gold standard, the relationship between scores and the degree of deviation of various bilateral biomechanical parameters from normality, future studies should analyze it. Additionally, the ability of the LGSI to discriminate individuals with a clinically relevant asymmetry should be objectively quantified. In these analyses, the potential normalization of the index to height should also be addressed, to see if it would improve or worsen the validity of the index. The repeatability of the LGSI should also be further explored. Specifically, future repeatability studies should be extended to clinical populations and should also assess the inter-assessor agreement and reliability. Finally, longitudinal studies should be conducted to assess the responsiveness of the LGSI to clinical interventions that are known to be effective and to lead to improvements in functional performance tests symmetry .A better solution might be to perform a weighted sum of the differences, assigning different weights to the variables according to their reliability or contribution to task success so that, for example, those variables known to be less reliable or less important to the task could contribute less to the overall score.

The repeatability of the LGSI should also be further explored. Specifically, future repeatability studies should be extended to clinical populations and should also assess the inter-assessor agreement and reliability. Finally, longitudinal studies should be conducted to assess the responsiveness of the LGSI to clinical interventions that are known to be effective and to lead to improvements in functional performance tests symmetry.

In the present study, the symmetry indexes were calculated in the statistical way, as follow.

Statistical decisions regarding reliability on the studies

All statistical analyses were performed using *SPSS (Version 24: IBM, Chicago, IL), Microsoft Office Excel, and Matlab software – (MathWorks, Inc.USA).*

For our statistical evaluations, some questions were analyzed, as follow bellow:

- Are individual’s measurements being truthful?
- The individual using instrument to measure own individual capacity on physical tests are reliable?

- How reliable and valid are this tests and also how reliable are intra-rater and intra-session?

For try to resolve this questions above, were applied the common way of statistical calculations most cited in sports science and clinical research literature through developed “reliable pack”.

The presence or not of heteroscedasticity was primarily checked visually with Bland–Altman plots with the magnitude of the mean with the absolute difference from test-retest (Atkinson & Nevill, 1998). Secondarily were identify heteroscedasticity and homoscedasticity of data and if was guaranteed normal distribution to try not carry-over effects between repeated tests.

Through *SPSS software (Version 24: IBM, Chicago, IL)* were statistically computed the variables, calculating with 95% of confidence interval (CI), the descriptive statistics, ratio, coefficient of variation (CV%), t-test (Kolmogorov–Smirnov test) for data with a normal distribution, Student’s t test was used, whereas for data with non-normal distribution, a nonparametric test (Mann- Whitney or Wilcoxon test) was used for comparison between the two groups. Also Pearson and Spearman correlations (for parametric and non-parametric test), linear regression bivariate (interaction between groups) and ANOVA models (interactions intra and inter- individuals pre and post functional tests and also between two different groups), were testes for all included variables*.*

Two-way random model, absolute agreement and consistency were utilized in *SPSS software* for calculations of relative and absolute reliability of discrete and continuous data measured outcomes from Functional Performance Tests. Also through *Microsoft Office Software Excel*, were calculated all rest of statistics data, including the ratio (R) coefficient of variation (CV), standard error of measurements (SEM), limit of agreement (LOA) with lower and upper limit of 95% confidence intervals (CI), kinetic and kinematic symmetry pre-post mean differences, standard errors of differences (SEMdiff), minimal detectible changes (MDC).

For easy comprehension of our statistical “reliable pack” calculation was implemented in our study, two variations of test-retest reliability evaluations of functional performance tests. They were:

A) Intra-rater (Relative reliability) and B) Intra-session (Absolute reliability) at 95% CI (Confidence intervals).

A) Relative reliability. The relative reliability was expressed as intra-class correlation coefficient (ICC) 95% confidence intervals (CI) for intra-rater reliability (Shrout & Fleiss, 1979) evaluating the random errors that may affect the relative test–retest (Atkinson & Nevill, 1998). According literature related to reliability of raters, instruments and performance tests, ICCs values of (0.41 to 0.96) indicating small to larger, (ICC 0.70) indicating satisfactory to good, (0.75) indicating good and higher (0.90) indicating excellent reliability (Atkinson & Nevill, 1998; Lohr et al., 1996; Segura-Ortí & Martínez-Olmos, 2011).

B) Absolute reliability. The absolute reliability describes the within-subject variability attributable to evaluations of repeated measures intra-session. This stablished statistical method is commonly used in sports medicine and physical therapy (Atkinson & Nevill, 1998; Bialocerkowski & Bragge, 2013; Haley & Fragala-Pinkham, 2006; Wagner, Rhodes, & Patten, 2008). The standard error of measurements (SEM) is a statistic reliability which quantifies measurement error in the same units as the original measurement. Commonly used to investigate different sources of individual variation or measurement error variance intra-session tests, indicating absolute agreement reliability with also 95%(CI).

"Reliable Pack" Statistical calculations.

Evaluating intra-rater, intra-session, test-retest reliability and minimal detectible changes of two symmetry indexes, kinetic and kinematic, where were retrieved in two different phases (pre and post) functional performance tests, between Lumbar SMT and SHAM interventions. All study was performed by researcher that cumulated tasks, since been a unique rater/observer that give ratings/trials from participants, performed the interventions (SMT and SHAM) in the same session, and processed, treated, calculated and analyzed all continuous data from study variables.

Nevertheless, our "Reliable Pack" measured outcomes from functional performance tests could demonstrate absolute and relative reliability, errors of measurements, minimal important changes detectible at the same time, especially because the same rater/observer measured and analyzed this protocol contained multiple ratings. i.e. (test-retest symmetry repeated measures in on day of data collection.

Intra-rater, test-retest, intra-session reliability was conducted in one day, constituting of 14 trials of functional performance tests for each participant. Thus, for all participants were totalized 560 trials.

The "reliable pack" aimed to evaluate the relative and absolute reliability of symmetry measured outcomes from physical performance tests, calculating the standard errors of measurements and minimal detectible changes.

The 95% of confidence interval (CI) applied in our study; represent a measure of the precision of an estimated value, normally expressed in the same units as the estimate. i.e (the limits intervals represents the range of values, consistent with the data, that is believed to encompass the "true" values". Thus, wider intervals indicate lower precision, and narrow intervals, greater precision).

By the way, this investigation tried to answer prior questions and produced precision results. The key question in the reliability of kinetic and kinematic parameters is whether the measures are reliable enough for clinical decision-making. Thus, our results presented large symmetry absolute and relative reliability, considered good to excellent confirming thus the accuracy of measurements, reproducibility intra-rater and intra-session agreements, drawing real effects produced by the SMT intervention proposed by our study protocol.

The relative statistical reliability was associated with ICC, that is recognized one of the most commonly reported reliability index, however, in our calculations was applied the model 3 (two-way mixed effects) is used when each subject is assessed by each rater but the raters are the only raters of interest (that in this case 1 rater). In this study the same rater (which was the only rater of interest) assessed each athlete participant, so the two-way mixed effects were the suitable model. In this way, in line with clinical and sportive scientific researches that works with 95% of confidence intervals, we could say that through all statistical analyzes described in our study, is safe to say that the “reliable pack” of measurements and analyses shows appropriate to serve in future studies. However, researchers should consider this method to measure local and global symmetry in physical performance tests, between SMT interventions, taking account the reliability, error of measurements and minimal detectible changes of the study variables.

Unfortunately, these conclusions are not the same in terms of validity, that needs more factors to analyze, construct and implement. Further studies with two or more groups (control and experimental), with measurement error analysis, more raters and with large sample size included, could increase much more the confidence of the kinetic and kinematic symmetry data, thus stablishing validity of the protocol with instruments/measurements.

The main findings are that some kinetic outcomes seem to be better post than pre phase, between lumbar SMT intervention, on functional performance test relative a lower limbs reaction forces symmetry. The results regarding these kinetic parameters from Group 1

(SMT) showed altered immediate effects on lower limbs reaction forces symmetry in Static Posture Trials on asymptomatic athletes.

This association between therapeutic intervention and symmetry never were deeply made, thus could be interpreted that exist causal effect related with (SMT- independent variable) and physical/functional performance tests (static, squat and CMJ) depended variable. The same results were not observed on Group 2, where for this groups calculated and analyzed outcomes measures of both symmetry indexes and of functional performance tests (pre, post differences), were not statistically significant and also not appear to be clinically and sportive meaningful. By the way, this randomized controlled study tried to answer prior questions and produced precision results. Thus, our results presented absolute and relative reliability considered good to excellent, confirming thus the accuracy of measurements, reproducibility intra-rater and intra-session agreements, drawing real effects produced by the SMT intervention proposed by our study protocol.

In line with clinical and sportive scientific researches that works with 95% of confidence intervals, we could say that through all statistical analyzes described in our study, is safe to say that the “reliable pack” of measurements and analyses shows appropriate to serve in future studies.

Our results indicated statistical significance on immediate improvement of bilateral kinetic symmetry in static posture, thus appear to be clinically and sportive meaningful. Thus, adding new information about the kinetic parameters in functional test influenced by lumbar SMT intervention, we expect to contribute with an important step in the clinical, academic and sportive context, being promise approach for next studies to objectively evaluate the real effect of SMT on biomechanics dysfunctions at local and global level. However, researchers should consider this method to measure local kinetic symmetry in functional performance tests namely Static Posture, between lumbar SMT interventions, taking account the reliability, error of measurements and minimal detectible changes of the study variables.

To our knowledge, this is the first study performed with health and asymptomatic athletes, that integrated knowledge’s about clinical rehabilitation and sports biomechanics, with focus on kinetic and kinematic symmetry assessment, and how measure, treat and evaluate to obtain accuracy of this measurements, drawing consistent result

Current planned submissions to publications

In our thesis, the planned submissions to publications in a high-impact peer reviewed journals count with our biomechanics laboratory team support with the procedures and decisions for new approaches, and encourage to submit for registrations and submissions in international platforms, according manuscript scientific publications recommendations. In this sense we expect to follow all requirements to submit to peer reviewed journals about the theme and share consistent and relevant results for all public community.

Also through scientific presentations in congresses and conferences, our team encourage us to submit and participate presenting our work from Biomechanics and Functional Morphology Laboratory team (BFML) - University of Lisbon.

Our common research interest is related development of experimental methodologies, modeling and simulation for the study of mechanical load on the musculoskeletal system; and also related on investigation of biomechanics effects of the application of Spinal Manipulative Therapy in recreational and elite athletes.

The datasets generated during and/or analyzed during the current investigation are/will be available upon request from the study contact. Each individual data (Individuals' biomechanical outcomes will be presented for study participants, showing outcomes related to performances tests symmetry and therapeutic intervention), will be share, starting from 2019, under previous communication and solicitation by study contact responsible personal, as indicated.

Recommendations for future research

Even though the present thesis shows that the is feasible, repeatable and reliable related with intra- rater, test-retest functional performance tests but further studies should be conducted to learn more about the psychometric properties for example, despite of the inherent subjectivity, it can be used in a clinical context to complement methodological protocol. Further cross-over study could be address to quantify symmetry/asymmetry, with two or more groups (control and experimental), with more rater, modified protocol or instruments, measurement error analysis, and large sample size. In this way, following this observations, next studies could increase much more the confidence of the kinematic symmetry data, drawing consistent kinematic outcome measures, thus stablishing validity of the protocol with instruments/measurements.

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Thesis related outcomes

First author paper in scientific journals

Published

Alvarenga B.A.P, Fujikawa R, Lara J.P.R, João F.O.S, Veloso, A. P. The effects of a single-session of lumbar spinal manipulative therapy in terms of physical performance test symmetry in asymptomatic athletes: a single-blinded, randomized controlled trial", BMJ Open Sport & Exercise Medicine.

Submitted

Alvarenga B.A.P, Botelho M.B, João F.O.S, Lara J.P.R, Veloso, A. P. Preliminary feasibility study to measure the immediate changes in symmetry after lumbar spinal manipulative therapy in asymptomatic athletes: Journal of Chiropractic Medicine (Under review R2)

Submitted

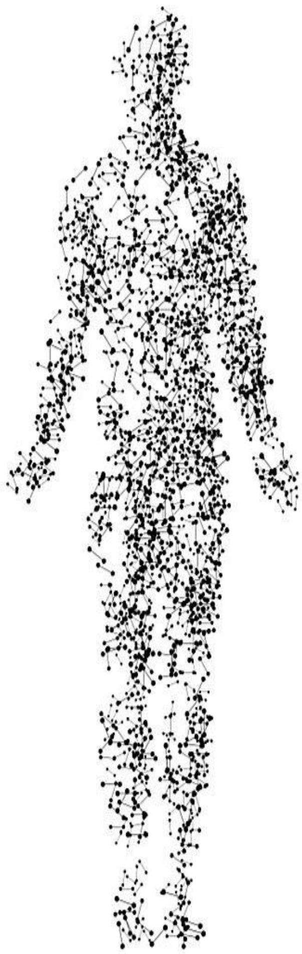
Alvarenga B.A.P, João F.O.S, Veloso, A. P. Intra-rater and Test-retest Reliability of Physical Performance Tests Symmetry between Lumbar Spinal Manipulation in Asymptomatic Athletes: Journal of Orthopaedic and Sports Physical Therapy (Under review R1)

Poster presentations

Alvarenga B.A.P, Botelho M.B, Lara J.P.R, Veloso, A. P. The immediate effects of Spinal Manipulative Therapy (SMT), in terms of performance tests assessment, on asymptomatic athletes (working in progress). Chiropractic & Manual Therapies 2017, 25 (Suppl 1):36 European Chiropractic Convention (ECU), May 24-27, 2017 Cyprus.

Alvarenga B.A.P, João F.O.S, Veloso, A. P. Test-retest reliability, standard error of measurement and minimal detectible change of physical performance tests symmetry, before and after lumbar Spinal Manipulative Therapy (SMT) in asymptomatic athletes: Imaging and device biomechanics: Modelling, diagnosis, rehabilitation, Jul 12th 2018, Dublin, Ireland.

Appendix 1



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Appendix 1: Compilation authorization

We, the co-authors of the article “A preliminary feasibility study to measure the immediate changes of bilateral symmetry after lumbar spinal manipulative therapy (SMT) in asymptomatic athletes”, submitted in 2018 in the Journal of Chiropractic Medicine, hereby authorize its inclusion in the thesis “The immediate effects of lumbar spinal manipulative therapy (SMT) in terms of kinetic and kinematic symmetry of functional performance tests on asymptomatic participants”, submitted by the PhD candidate Bruno Araújo Procópio de Alvarenga.

Cruz-Quebrada, 20th Março, 2019

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(Bruno A. P. Alavarenga)

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(Marcelo B. Botelho)

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(Filipa O.S. João)

____

(Jerusa P.R. Lara)

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(António P. Veloso)

Appendix 2: Compilation authorization

We, the co-authors of the article “Intra-rater and Test-retest Reliability of Physical Performance Tests Symmetry between Lumbar Spinal Manipulation in Asymptomatic Athletes”, submitted in 2018 in the Journal of Orthopaedic and Sports Physical Therapy, hereby authorize its inclusion in the thesis “The immediate effects of lumbar spinal manipulative therapy (SMT) in terms of kinetic and kinematic symmetry of functional performance tests on asymptomatic participants”, submitted by the PhD candidate Bruno Araújo Procópio de Alvarenga.

Cruz-Quebrada, 20th Março, 2019

____
(Bruno A. P. Alavarenga)

____
(Filipa O.S. João)

____
(António P. Veloso)

Appendix 3: Compilation authorization

We, the co-authors of the article “The effects of a single-session of lumbar Spinal Manipulative Therapy (SMT) in terms of physical performance tests symmetry in asymptomatic athletes: a single-blinded, randomized controlled study”, published in 2018 in the BMJ Open Sport & Exercise Medicine, hereby authorize its inclusion in the thesis “The immediate effects of lumbar spinal manipulative therapy (SMT) in terms of kinetic and kinematic symmetry of functional performance tests on asymptomatic participants”, submitted by the PhD candidate Bruno Araújo Procópio de Alvarenga.

Cruz-Quebrada, 20th Março, 2019

____
(Bruno A. P. Alvarenga)

____
(Ricardo Fujikawa)

____
(Jerusa P.R. Lara)

____
(Filipa O.S. João)

____
(António P. Veloso)

Appendix 4: Information letter

Dear participant, welcome and thank you for being part of this study. (Translated from Portuguese)
Title of the research project: The immediate effects of lumbar spinal manipulative therapy (SMT) in terms of kinetic and kinematic symmetry of functional performance tests on asymptomatic participants.
Name of Supervisor(s): Prof. António Prieto Veloso
Name of co-supervisor: Prof. Filipa O.S. João
Name of Research student: Dr. Bruno Alvarenga
Name of Institution: FMH – Faculty of Human Kinetics
Introduction and Purpose of the study: This study hopes to show that Spinal Manipulative Therapy has a positive outcome on asymptomatic participants in terms of performance tests assessment. This particular study pertains to 40 participants or more depending of elegitibility process.
Procedures
The visits: Each participant will be required to commit to two visits at Biomechanics lab. The Biomechanics Lab. is located into (FMH) Faculty of Human Kinetics, University of Lisbon, Cruz Quebrada, Portugal. The initial consultation will include a (IPAQ) questionnaire and Physical Exam, with case history, posture assessment, low back regional examination to determine participant suitability. Once participants have been accepted onto the study, they will be divided into groups 1 and 2. For the purposes of this study participants falling in group 1 will receive therapeutic intervention, (i.e. SMT) and those participants falling in group 2 will act as the control group receiving SHAM pre-positioning (SMT) intervention. At the initial consultation both groups will have their make 3 trials of Free Squat and Vertical Jump (CMJ) (performance tests assessment), before the interventions.
Once the averages of the performance tests have been determined, the researcher will intervene with the relevant Spinal Manipulative Therapy (SMT) (should you fall in group 1) and (SHAM) (should you fall in group 2). This will then be followed immediately by another set of performance tests (Post-intervention) of readings for which an average also, will be calculated.
Risks/Discomfort:
Minimal Risk. Please note that Spinal Manipulative Therapy (SMT) can cause some post

treatment stiffness for 24 hours, but it is a rare side effect and not present in all participants.
Benefits:
By participating in this research you will be able to find out if you have weak or strong lower limbs muscles and if you improve symmetry and countermovement jump high (CMJ), after intervention. Studies have shown that bilateral asymmetries, can lead to future episodes of low back pain. Therefore, should you have symmetry of the lower limbs muscles, you may be able to prevent future low back disorders. There will be no charge to the participants involved in this study and the (SMT) intervention provided will be according to normal clinical practices.
New findings: Each participant has the right to be informed of any new findings that are made relevant to this particular study.
Reasons why you may be withdrawn from this study without your consent: 1. If you experience extreme pain on Physical Exam, are being assessed. 2. If you experience extreme pain on Performance tests assessment, are being assessed. Please also note that any participant can withdraw from the study at any time without supplying a reason.
Remuneration/Cost of the study: Please note that there will be no remuneration at all pertaining to this study and that your participation is completely voluntary.
Confidentiality: All participant information related to this study is confidential and the results will be used for research purposes only. Note however that supervisors and co-supervisor, will have access to these records. The others staff members will not have permission to access theses records. Contact details regarding any problems or questions pertaining to the study: Should you require answers from an independent source (i.e. co-supervisor) please feel free to contact them. If you are not satisfied with any area of this study, please direct your queries and concerns to the Biomechanics Laboratory Team and the Ethics Committee, at FMH.
Thank you again for your participation in this study.

Bruno Alvarenga	António Veloso	Filipa João
(Researcher)	(Supervisor)	(co-supervisor)
(351) 9260 93165		

Appendix 5: Informed Consent Term

(To be completed by research participant) Translated from Portuguese
Title of the study: The immediate effects of lumbar spinal manipulative therapy (SMT) in terms of kinetic and kinematic symmetry of functional performance tests on asymptomatic participants.
Name of Supervisor(s): Prof. António P. Veloso
Name of co-supervisor: Prof. Filipa O.S João
Name of Research student: Dr. Bruno Araújo Procópio de Alvarenga
Name of Institution: FMH – Faculty of Human Kinetics – University of Lisbon
Signature of Informed Consent, Free and Informed
I read (or someone read to me) the present paper and I am aware of what to expect regarding my participation in the study. I had the opportunity to put all the questions and the answers clarified all my doubts. Thus, I voluntarily accept to participate in this study. I have been given a copy of this document**.**
Participant Name: **Participant Signature:** **Researcher / Investigation team:** **Date:**
The most important aspects of this study were explained to the participant or their representative before requesting their signature. A copy of this document will be provided to you.
Name who received the Consent **Signature who received the Consent**

Appendix 6: Ethic Commitment

Tittle of the Study: The immediate effects of lumbar spinal manipulative therapy (SMT) in terms of kinetic and kinematic symmetry of functional performance tests on asymptomatic participants
Responsible person for the project: Bruno Araújo Procópio de Alvarenga
Institution: laboratory of biomechanics and functional morphology - FMH 1. I consider thank you to know and respect human rights. 2. I consider that I am required to comply with national and international ethical principles, including the "Oviedo Convention" (1997), the "Geneva Declaration" (2002), the "Helsinki Declaration" and amendments (2008). 3. In all my actions I will keep the ethical attitude that moral demands and meets its legislation in vigor. 4. I will not wake off with no prior notification of the procedures exposed in the project that continue with the ethical principles assumed. 5. I consider that I obligate to individually clear each participant of the study on the purpose of the same and on the procedures to which it will be subject. 6. Believe that I do not use procedures that complete the moral and physical integrity of the participants and I will take into account the relationship between the possible utility of the results and the set of the procedures performed. 7. Even though the participant's annuity will not practice acts who against your life or against your health, physical or mental. 8. I will avoid all unnecessary or unsolicited procedures. 9. I will not use data or results which rather the good name or the integrity of the participants.
SIGNATURE OF THE RESPONSIBLE PERSON BY THE PROJECT OR STUDY

Appendix 7: Check-List data collection

	Data collection task`s sequence	Check	Partial time	Total time
1	Placing my lap top on the table and turn it on.	x	-	
2	Arrange the records of the participants.	x	1 min	
3	Placing marks on the ground for the placement of the feet on the surface of the force platform.	x	1 min	
4	Connecting the computer of collections of LBMF with the force platforms.	x	1 min	
5	Positioning of the 15 cameras, image adjustment each and check the center of pressure on the force platforms.	x	5 min	
6	Calibration of space.	x	5 min	
8	Participant arrival.	x	1 min	
9	Procedures explanations to participants.	x	2 min	
10	Researcher perform Chiropractors tests (checking the presence of lumbar spinal dysfunction).	x	5 min	
11	Marking of points regarding the reflectors markers, using the graphic-skin pencil.	x	3 min	
12	Putting on 49 reflective markers and 6 clusters, on the trunk and legs of the participants.	x	5 min	
13	Participant on orthostatic position - Static I (Pre) Record.	x	2 min	
14	Free squat performed on 2 force platforms (3 repetitions).	x	3 min	
15	Maximum vertical jump height (3 CMJ jumps on 2 force platform).	x	5 min	
16	Take off reflective markers and clusters, and preparing to next step preparation.	x	3 min	
17	Realization of SMT and SHAM procedures.	x	3 min	
18	Putting on 49 reflective markers and 6 clusters, on the trunk and legs of the participants.	x	5 min	
19	Participant on orthostatic position - Static II (Post) Record	x	2 min	
20	Free squat realization on the force platforms (3 repetitions).	x	3 min	
21	Maximum vertical jump (3 CMJ jumps on 2 force platform).	x	3 min	
22	Take off reflective markers and clusters, and take a rest. Athlete leave the laboratory.	x	2 min	
				60 Min

Appendix 8: International Questionnaire of Evaluation of Physical Activity (IPAQ)

Name:____Date: ________

IPAQ-Short version (Portuguese version translated)

This questionnaire includes questions on physical activity usually done to move from side to side, at work, in household activities (male or female), gardening and the activities they carry out in their free time for entertainment, exercise or sport. The questions concern the physical activity carried out in a normal week in exceptional and not days, for example, on the day we made the change of the house. By answering the following questions consider the following: vigorous physical activity refers to activities that require a lot of physical exertion and breathing becomes much more intense than usual. Moderate physical activity refers to activities that require moderate physical exertion and breathing gets a little more intense than normal. When answering questions only consider physical activities to undertake for at least 10 consecutive minutes.

Please answer all the questions even if not considered an active person.

1a During the last week, how many days did vigorous physical activity such as lifting and / or carrying heavy objects, digging, perform aerobics, running, swimming, playing football or cycling at an accelerated rate?

________days for week

________none (follow to 2ª question)

1b How long in total spent in these days, to realize vigorous physical activity?

________hours_________minutes

2a During the last week, how many days did moderate physical activity such as lifting and / or carrying light loads, cycling at a moderate speed, domestic activities (i.e: scrubbing, vacuuming), gardening, doing carpentry work, play tennis table? Do not include walking / hiking.

________days for week

________none (follow to question 3a)

2b How long in total spent in these days, performing moderate physical activity?

________hours_________minutes

3a During the last week, how many days went / walked for at least 10 minutes at a time? Include walks to work and home, to move from one side to another and any other walk you can do only for recreation, sport and leisure.

__________days a week

__________No (skip to question 4a)

3b How long, in total, spent one of these days to walk /hike?

________Hours_________minutes

3c How rapidly usually walk?

______Vigorous, who takes his breath much more intense than usual;

______Moderate, it takes your breath a little more intense than normal;

______Slow, it does not cause any change in your breathing.

The latest questions refer to the time you are sitting at work every day, at home, on the way to work and during leisure time. These issues include for example the time you are sitting at the table or desk, visiting friends, reading or sitting / lying watching TV.

4a How long, in total, he spent sitting (a) during one of the weekdays (Monday to Friday)?

_________hours_________minutes

4b How long, in total, he spent sitting (a) during one of the days of end-of-week (Saturday or Sunday)?

_________hours_________minutes

Thank you for your participation!

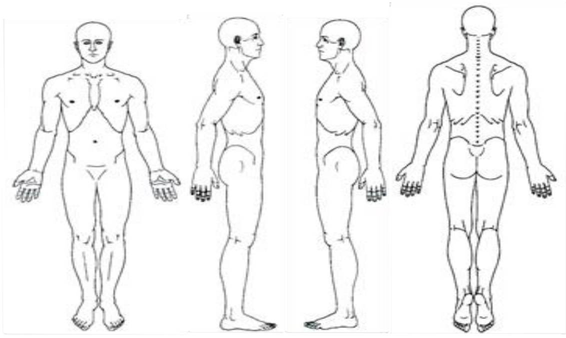
Appendix 9: Physical and Clinical Exams

Name:			Date:
Weight (Kg):	Height (m):	Age:	Birthday:
General Aspect:			
Anamnesis:			

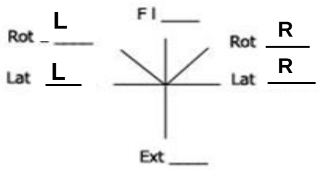
Case History
1. Source of History:

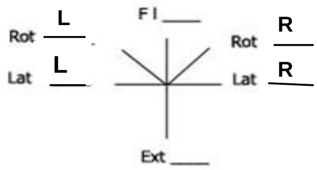
2. Chief Complaint (participant own words):
3. Medications:
4. Complement Exams:

Postural Assessment

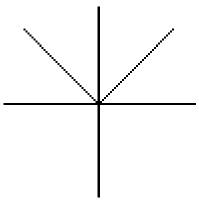
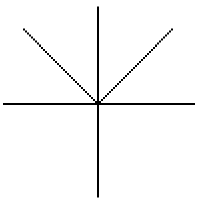
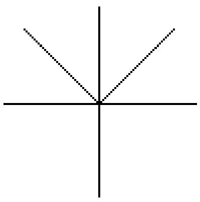
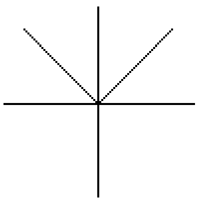


Lumbar Vertebras Range of Motion (ROM)





Lumbar Vertebral Dysfunction

Level:	Level:	Level:	Level:
			

Appendix 10: Clinical Trials Register ISRCTN Receipt

BMC
Part of Springer Nature

ISRCTN registry

Search | Advanced Search

View all studies | Why register? | Register your study | BRUNO ALVARENGA | My Account | Logout

My Account

Name BRUNO ALVARENGA
Address
Email brunofisioquiro@hotmail.com
Phone

Edit account details | Edit password

My Trials

Published trials

Title	Editorial status	Reference number	Date submitted	Action
Changes in lower limbs reaction forces symmetry after Spinal Manipulative Therapy (SMT)	Published	ISRCTN10744300	12/12/2017	Request update

Appendix 11: Clinical Trials Register PRS Receipt

ClinicalTrials.gov PRS
Protocol Registration and Results System

ClinicalTrials.gov Protocol Registration and Results System (PRS) Receipt
Release Date: December 4, 2017

ClinicalTrials.gov ID: NCT03361592

Study Status

Record Verification: December 2017

Overall Status: Active, not recruiting

Study Start: September 4, 2017 [Actual]

Primary Completion: September 22, 2017 [Actual] Study
Completion: December 5, 2017 [Anticipated]

Sponsor/Collaborators

Sponsor: University of Lisbon

Responsible Party: Principal Investigator
Investigator: Bruno Araújo Procópio de Alvarenga, PT, DC [balvarenga]
Official Title: Phd Student, Physiotherapist and Chiropractor
Affiliation: University of Lisbon

Collaborators: Coordenação de Aperfeiçoamento de Pessoal de Nível Superior.

Oversight

U.S. FDA-regulated Drug: No

U.S. FDA-regulated Device: No

U.S. FDA IND/IDE: No

Human Subjects Review: Board Status: Approved
Approval Number: #31
Board Name: Ethics Committee of the Faculty of Human Kinetics (CEFMH)
Board Affiliation: University of Lisbon
Phone: (+351) 214149100
Email: etica@fmh.ulisboa.pt
Address:

Contacts/Locations

Central Contact Person: Bruno Alvarenga, Phd
Telephone: (351)926093165 Email:
brunofisioquiro@hotmail.com Central Contact Backup:

Study Officials: Bruno Alvarenga, Phd
Study Principal Investigator
ULisboa

Locations: Portugal
Bruno Araújo Procópio de Alvarenga
Lisbon, Portugal, 1700-228
Contact: Bruno Alvarenga 926093165 brunofisioquiro@hotmail.com

Appendix 12: FMH Ethics Committee Submission Receipt

FMH FACULDADE DE MOTRICIDADE HUMANA

Conselho de Ética

MEMBROS
Pedro Teixeira (Presidente)
Paulo Armada (Vice-presidente)
Anabela Silva
Ana Rodrigues
Augusto Gil Pascoal
Paula Maria Bruno
Celeste Simões
Hermínio Barreto (supl.)

Para:

Dr. Bruno Alverenga
Faculdade de Motricidade Humana

Data: 19 de setembro de 2017

Projeto: "The immediate effects of Manipulative Vertebral Therapy (MVT), in terms of symmetry on Performance Tests Assessment, in young active participants"

Estado CEFMH: Positivo

Parecer CEFMH N.º: 31/2017

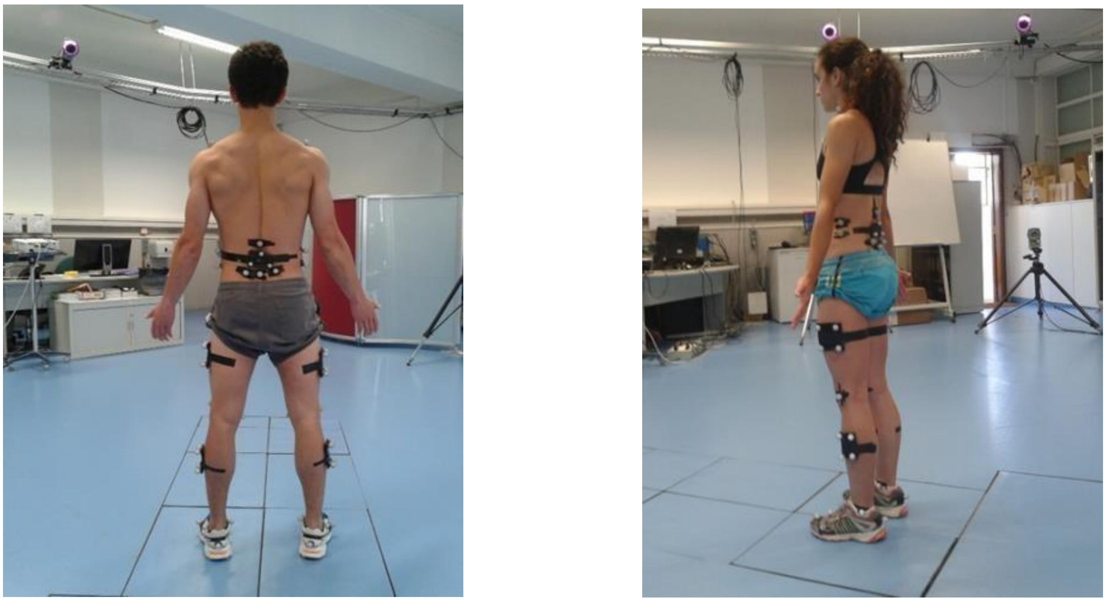
Este Conselho analisou o projeto em epígrafe. Confirma-se que o mesmo está em conformidade com as diretrizes nacionais e internacionais para a investigação científica que envolve seres humanos, incluindo a Declaração de Helsínquia sobre os Princípios Éticos para a Investigação Médica em Seres Humanos (2013) e a Convenção sobre os Direitos do Homem e a Biomedicina ("Convenção de Oviedo", 1997).

O Vice-Presidente do Conselho de Ética da FMH

Paulo A. S. Armada da Silva

Conselho de Ética da Faculdade de Motricidade Humana, Universidade de Lisboa
Faculdade de Motricidade Humana
Estrada da Costa, 1495-688 Cruz Quebrada - Portugal
etica@fmh.ulisboa.pt

Appendix 13: Picture of data collection capture



Picture with posterior and lateral view of participants performing Static Posture Trials (pre and post intervention) maintenance for 10 seconds, as a part of functional performance tests (picture of athlete participant with permission).

Picture Left: posterior view of lumbar SMT intervention position, performed by researcher B.A.P.A. Picture Right: front view of SHAM pre-positioning lumbar SMT, showing participants receiving SHAM maintenance positing by researcher B.A.P.A (picture of athlete participant with permission).